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**ABSTRACT**

An analysis was made of the perceptual characteristics of the pilot's visual world while performing various flight tasks. These were compared with the perceptual characteristics made available by typical non-programmed visual displays attached to flight trainers. An experiment was then conducted in the F-100 simulator equipped with the 151 visual attachment to determine training effects. It was determined that, even among experienced subjects, performance significantly improved, both with regard to (1) the detection of inflight emergencies and (2) the maintenance of aerodynamic stability. Recommendations are made for improvements in external visual displays to enhance the training value of flight simulators.

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Technical Report: NAVTRADEVCEM 783-1

THE PILOT'S VISUAL TASK:

A STUDY OF VISUAL DISPLAY REQUIREMENTS

F O R E W O R D

This study was designed to optimize the contribution that flight trainers equipped with non-programmed visual attachments can make to the learning of visual reference flight skills, especially of those vital to flight safety. It was therefore necessary to analyze the visual world of the pilot from the mathematical-perceptual viewpoint and compare it to the simulated world created by two current attachments; to determine which training needs could best be met by these and similar attachments; and to conduct an experiment on the nature of flight skills that entail complex time-sharing patterns between intra- and extra-cockpit visual cues.

The study reveals the value of appropriate non-programmed visual attachments for formation-flight and collision-avoidance training; emphasizes the need for cockpit motion in flight simulators, especially when visual attachments are used; yields numerous specific solutions to persistent problems in the design of such attachments; and makes detailed recommendations for the improvement of the Dalto and the 151 visual attachment to the F-100 simulator. Finally, it describes the role of visual attachments in research and explains how they can promote the scientific study of vertigo, of pilot behavior during emergencies, and of appropriate visual time-sharing patterns.



George Chajet  
Project Psychologist

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## SECTION I

## CONCLUSIONS AND RECOMMENDATIONS

A SETTING FOR THE CONCLUSIONS AND RECOMMENDATIONS

The operational flight trainer with an external visual display offers an opportunity to practice those aspects of flight requiring external visual cues. Simulators without visual attachments have been mainly used as procedures trainers. The practical fact in aviation, however, is that pilots do utilize information from two visual worlds; hence, they require practice in a variety of visual tasks involving the integration of information from inside and outside the cockpit. It is known, for example, that landing and takeoff accidents represent a significant part of the total accident picture, and one of the most significant skills used by a pilot in landing and takeoff is his visual estimation of sink rates, accelerations and decelerations, closing rates, depth, and orientation relative to the runway. For this reason, the U. S. Naval Training Device Center initiated this study toward the following objectives:

Objective #1 -- Objective #1 was to determine the nature of the pilot's visual task. Such a determination is essential for the design of attachments to OFT's that are intended to provide training in crucial contact-flight tasks such as landing, collision-avoidance, and formation flying. Since these attachments commonly simulate changes in the pilot's visual world as a function of his control movements, they are called "nonprogrammed visual attachments to flight trainers."

Objective #2 -- The second objective was to examine intensively two visual attachments - one by expert observation, the other by experimentation - to determine their actual and potential training value; and to discover additional characteristics that might be needed to more fully meet the requirements for synthetic contact-flight training. The two attachments and the associated flight trainers were:

LOCATION	TYPE OF FLIGHT TRAINER	VISUAL ATTACHMENT
NAFEC Atlantic City, New Jersey	P3A Manufacturer: Curtiss-Wright Serial No. 537	Dalto Manufacturer: DALTO Corp. Serial No. 1
NAFEC Atlantic City, New Jersey	F-100A Manufacturer: Union Switch and Signal Corporation Serial No. 54-1	151 Manufacturer: Rheem Manufacturing Company Serial No. 55-151-1

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The conclusions and recommendations which follow were drawn from the above efforts, but were gathered together in three major functional areas:

Area #1 -- Conclusions and recommendations concerning the training potential of nonprogrammed visual attachments.

Area #2 -- Conclusions and recommendations concerning the perceptual characteristics of visual flight as made in the specific nonprogrammed visual attachments.

Area #3 -- Potential applications of the nonprogrammed visual attachment to the OFT to the: (1) investigation of vertigo; (2) detailed analysis of pilot behavior in the cockpit; and (3) detailed analysis of the visual behavior of pilots, and the difference between experienced and inexperienced pilots in this regard.

### A. AREA #1--TRAINING POTENTIAL OF NONPROGRAMMED VISUAL ATTACHMENTS

The experimental results, the information obtained from pilot-interviews, and the observations and analyses of the research staff all lead to the conclusion that visual attachments to OFT's can make a significant training contribution. Improvements occurred not only in the overall ability to fly, but also in the ability to more quickly detect intruder aircraft and own-aircraft emergencies. The conclusions and recommendations which follow set out training areas to which the visual attachment could be applied, as well as modifications which are necessary in current attachments in order to obtain fullest use from them.

One overall concept should be kept in mind in considering these recommendations, and the general tenor of this report. This concept is the one of time-sharing. The word 'time-sharing' represents the division of the pilot's visual behavior or attention among his various major tasks, and then within each of these, the division of his time among the sub-tasks. In order to discuss the visual behavior of pilots or to compare their learning as a result of training, we must start with some basic situation which can be described in terms of their visual behavior. For example, a pilot in the fog (literally speaking) can only share his visual behavior within the cockpit, whether it be for navigation purposes or for detecting emergencies presented therein. In clear weather, he now is called upon to further divide his visual behavior between the inside cockpit information and the external world, thus obviously giving him less time to detect within-the-cockpit information. In the experimental work reported here, we tried to equate inside and outside emergencies using visual time-sharing as the basis for our equation. Although this concept of visual time-sharing may seem obvious, we believe it is a concept

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lacking in much of the work relating to instrumentation, cockpit configuration and accident prevention, so that it needs emphasis here and throughout this report.

Recommendation #1 -- Training in visual time-sharing is needed, even by highly skilled pilots. This is supported by the fact that the pilots in this study who performed best in aircraft control did not necessarily perform best in emergency detection; in fact, the relationship between aircraft control and emergency detection was close to zero.

Recommendation #2 -- The fact that both the reciprocating engine pilots, as well as the jet qualified pilots showed great improvement in emergency detection behavior indicates that this particular trainer (F-100/151) could be used for transition training as well as for refresher training. This statement can be made because this jet aircraft simulator served, in part, as refresher trainer for the jet pilots, and as transition training for the reciprocating pilots.

Recommendation #3 -- The interviews revealed that a major reason for the highly motivated performance in the F-100/151 trainer was its visual display, which enabled the practice of the realistic and difficult time-sharing between intra- and extra-cockpit cues. Even if the external display were to serve no other useful function, it would at least serve to increase the motivational level of the trainees. It is recommended that a "sales pitch" be given concerning the external visual display so as to motivate the trainees not favorably disposed toward flight simulators.

Recommendation #4 -- In the design of flight trainers equipped with visual attachments, the problem of cockpit-motion and "seat-of-the-pants" cues must be carefully considered. The need for definite decisions concerning these body cues can not be escaped, since even in a motionless trainer such as the F-100/151 body-movement was experienced. Furthermore, if cues for acceleration are to be taught, cockpit-motion is necessary since the best cue-patterns are not visual alone, but contain vestibular\* and proprioceptive elements.

Recommendation #5 -- Pilots should obtain a more explicit understanding of the extra-cockpit cues needed in difficult contact-flight tasks. They should know the implications of these cues for each maneuver; the interactions among them; and the conditions under which ambiguities and illusions may occur. The functional analyses given later in this report (pages 10 - 38) are of medium difficulty - approximately midway between intuitive, non-verbal knowledge, and advanced perceptual-psychological theory - and could serve as source material for this type of training.

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\* See Glossary, p. 118.

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Recommendation #6 -- Wherever there exist cues or patterns of cues that can give the pilot immediate and reliable information for his visual tasks, they should be taught directly with the aid of visual displays. This would eliminate the need to acquire cues haphazardly and to spend too much time in sifting and interpreting unreliable cues during actual flight.

### B. AREA #2--PERCEPTUAL CHARACTERISTICS OF VISUAL FLIGHT

Recommendation #1 -- It is advisable to include cockpit motion ("seat-of-the-pants") cues in contact simulators. If the simulation of a wide range of cockpit motion cues is not feasible, at least some of them should be provided; for example, the use of a pressure suit might substitute for g-forces. The lack of these cues has many serious consequences, for example, training cannot be given in the dangerous illusions the pilot encounters; another is that the lack of these cues may disturb proper time-sharing in that the pilots may be forced to look at certain instruments more often than usual, for example, the g-indicator. In almost all cases, the pilots in the present study exceeded the "g" limitation in the F-100/151. Very often the subjects attributed all apparent movement solely to the target aircraft in the situation rather than to their own aircraft and the target in combination. This is also indicative of the need for the simulation of these cues.

Recommendation #2 -- Great care must be taken to free visual attachments from cues not present in the real world situation. Such cues help learn to fly the simulator, but do not yield positive transfer to the real world. E.g., in the display component of the P3/Dalto, the edge of the screen provides cues for roll and pitch which the pilot will never have in actual flight.

Recommendation #3 -- An important cue in estimating the distance, and the changes in the distance of a target, is the degree of the target's contrast with the background. E.g., as the target recedes from the pilot, it loses contrast because of atmospheric attenuation. It is recommended that changes in the distance of simulated targets on the 151 or similar displays be accompanied by appropriate changes in atmospheric attenuation.

Recommendation #4 -- It is recommended that "grain of wheat" lamps or some other devices with a similar effect be used for the Dalto landing display. This would result in making the simulated runway lights actual sources of illumination and therefore permit the closer ones to appear brighter and more distinct than the ones further away. Thus, the relative brightness of the runway lights could be used as a cue for depth as well as resolution of detail. At present, reflected light is being used which cannot provide a gradient of apparent brightness or distinctness, and therefore results in a loss of cue realism.

Recommendation #5 -- Textural details of target aircraft are needed by the pilot during formation flight and should be simulated on 151-type displays. An optical display suitable for this purpose is currently being developed at NAFEC by Drexel Engineering.

\* The National Aviation Facilities Experimental Center, Atlantic City, New Jersey.

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Recommendation #6 -- The horizon should be carefully simulated in all displays for contact flight tasks (except night landings) because the perceived distance between an object and the horizon is one of the most vital cues to be learned.

Recommendation #7 -- It is highly necessary to reduce lags between flight-simulator controls and the resultant displays on the visual attachment; as well as between flight simulator controls and the cockpit instruments. In the case of the P3/Dalto these lags are excessive and result in considerable lack of realism.

Recommendation #8 -- Yaw information is needed in most contact flight tasks and should be provided on the 151 and similar displays. This requires a textured and more irregular horizon than is present in the 151 display.

Recommendation #9 -- Visual displays should provide a wide range of general levels of illumination, as well as of contrast ratios between sky and ground. If this range is lacking (as it is in the 151), the horizon is not sufficiently prominent, and a poor time-sharing pattern, with over-dependence on cockpit instruments under VFR, may result.

Recommendation #10 -- Although none of the subjects used in the present study observed any deviation from realism associated with horizon elevation, it is known that in the real world situation the elevation of the horizon decreases with increased altitude. This was not duplicated in the 151 display and perhaps should be incorporated for maximum realism.

Recommendation #11 -- It is essential that the horizon be simulated to appear at infinity. Some pilots in this study complained that the horizon in the F-100/151 seemed too close.

Recommendation #12 -- Cues of texture compression should be simulated in daytime landing displays. These cues include such features as skid marks, cracked concrete, and earth scars.

Recommendation #13 -- The perceived shapes of buildings and other objects of distinct form serve as important cues for altitude during landing. It is advisable to provide visual displays with the capability of representing such cues for a wide variety of daytime landing situations.

Recommendation #14 -- Interposition, i. e., the partial hiding of one object by the object in front of it, is a good cue for distance. Interposition cues are now lacking in the Dalto and other displays and should be added.

Recommendation #15 -- Dalto-type displays should provide for easy changing of simulated runway-width. If runways vary in width in the real world situation, practice with only one width may result in undershooting or overshooting during an actual landing.

**C. AREA #3--POTENTIAL APPLICATIONS OF THE NONPROGRAMMED VISUAL ATTACHMENT TO THE OFT**

Out of this study have come some clear potential applications of non-programmed visual attachments to the study of urgent problems in aviation. These are presented as recommendations below.

Recommendation #1 -- It can be concluded that the F-100/151 offers excellent potential to investigate vertigo as a pressing aviation problem. Almost all of our subjects developed some symptoms of vertigo in this trainer, either in the form of disorientation or in the form of hallucinating movement. (No actual cockpit movement existed, since this is a stationary trainer.) From this study, it is the belief of the research staff that vertigo represents a deficiency in the ability of the pilot to receive and resolve conflicting information. Using a simulated situation which a visual attachment like the F-151 provides, it would be completely possible to systematically introduce a wide variety of orientation data in such a way that we could determine some conditions under which different pilots begin to hallucinate or become the victims of a vertiginous state. Thus we would have a method for identifying the relatively "vertigo-prone" pilot; and a research tool in which vertigo, and techniques of getting out of it could be systematically investigated.

Reduction of vertigo is vital not only to the prevention of accidents in general; but also to the prevention and proper handling of stall/spin incidents, as well as to effective ejection during spins. In stall/spin accidents -- which comprise from 3% to 10% of high performance Naval aircraft accidents -- it is essential that the pilot know which way the aircraft is spinning. The spin characteristics of certain aircraft, notably the F8U-2N\* are such that it sometimes seems to the pilot that the direction of spin is reversing even though it is not. Synthetic training in the ability to re-establish orientation is especially important since intentional spins are not permitted in most high performance Naval aircraft.

Recommendation #2 -- Using the concepts and techniques of time-sharing research that have emerged from this study, optimum time-sharing patterns should be described for given flight tasks and given aircraft-types. Once known, such patterns can be directly taught to students, just as in World War II, lookouts were trained in optimal search patterns for intruder detection. Furthermore, these time-sharing patterns can serve as guidelines for developing pilot-performance criteria; for designing training devices; as well as for estimating pilot loads imposed by new instrumentations and cockpit configurations for actual aircraft.

Recommendation #3 -- A third recommendation is to apply the nonprogrammed visual attachment coupled with the head camera to the analysis of visual learning

\* Bureau of Naval Weapons. Flight Manual. Navy Model F8U-2N Aircraft. NW01-45HHD-1.



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in the cockpit. This is closely related to the recommendation above, but represents a more detailed look at the learning process as a sequence of events as opposed to the verbal description of visual time-sharing by the pilot. These more intensive analyses should be able to pinpoint the otherwise hard-to-detect differences in the learning and in the visual behavior of pilots who are successful versus those who are not successful in aerial refueling and other critical visual tasks. Such use of the head camera would also help identify the subtle differences in the visual component of the aerial refueling task imposed by differences in aircraft. We believe it is feasible to simulate these applications now, even with the available nonprogrammed visual attachments. It should be noted that in all of the analyses above, a continuing attempt would be made to corroborate the visual behavior in the simulator with visual behavior in the real flying situation. This matching of the two situations, however, need not be an extensive task, hence the majority of the research could be on the ground.

## SECTION II

### THE ANALYSIS OF THE PILOT'S PERCEPTUAL TASK

#### A. INTRODUCTION

1. **THE OVERALL TASK.** The overall task of this research required an investigation of the perceptual characteristics of the pilot's visual world. This section of the report treats the perceptual characteristics of:
  - a. The pilot's visual world while performing various flight tasks; and
  - b. The nonprogrammed visual displays attached to flight trainers.

The training potential of these devices with respect to jet pilots and reciprocating engine pilots are considered in Section IV.

2. **STATEMENT OF THE PROBLEM.** The perfect flight trainer, by definition, would permit the trainee to transfer directly from it to solo flight. This goal is currently unachievable, but the greater the fidelity of the trainer to the real world situation, the closer the approach to this objective. The extent of congruity between the aircraft and the flight trainer with respect to machine inputs, external environment inputs, and operator outputs must be investigated for each and every task that the pilot is called upon to cope with. In other words, the correspondence necessary will vary with the flight task. For example, while monocular cues may be sufficient for simulation of the landing task, binocular cues may be required for proper simulation of the tasks of formation flying and inflight fueling.

On the basis of the perceptual analysis of the pilot's part-task and a perceptual analysis of the nonprogrammed visual displays, it will be possible to make an expert evaluation of the amount of correspondence or discrepancy existing between the pilot's visual world and the nonprogrammed visual display. From this evaluation, recommendations and specifications will be given for future developments in visual displays for inflight refueling and other critical contact flight tasks.

In this evaluation we must consider which sensory cues may be left out, and which cues must be left in the visual display. Two considerations are important here.

First, only the sensory cues which are essential for governing the perceptual-motor skills required in the part-task being simulated need

be duplicated; there is no need to recreate the entire visual world. For example, atmospheric attenuation (which causes distant objects to look almost gray) need not be completely duplicated in every visual attachment even though it does provide the pilot with a cue for distance. Another example is color; it is quite likely that color as a cue to distance could be eliminated from the nonprogrammed visual display without interfering with its training potential. (Lybrand et al. 20)

Secondly, sensory cues which are helpful in "flying" the flight trainer, but which are either not available, or have a different meaning, or possess tracking rates different from those encountered when flying an actual aircraft, must be rigorously excluded from the visual simulator. Such a cue might be the edge of the projection screen which serves to provide the trainee with a spurious horizon. If he uses the edge of the projection screen to land successfully while training, he will experience severe difficulties when he has to land actual aircraft in the absence of the cues (edge of projection screen) he had previously used.

In spite of the large amount of work done, there is a serious lack of reliable empirical information concerning which cues are essential to the performance of visual reference maneuvers. The work of Lybrand, et al. (20) is good, but only attempts to cover the landing task. Furthermore, it does not incorporate the theoretical and empirical approach taken by Calvert (3) who has analyzed the essential information requirements of the pilot's visual world by means of geometry of perspective. As far as the analysis of nonprogrammed visual displays is concerned, we have the work of Molnar and Lybrand (22). This study, while satisfactorily treating the component hardware in great detail, does not represent an analysis and evaluation of the perceptual characteristics of the nonprogrammed visual displays.

Another deficiency in the area of flight trainer analysis which needs to be remedied is the failure to analyze the pilot's task from a dynamic, global viewpoint. This is the problem of time-sharing. The pilot does not stare out of his cockpit at the external visual world; he distributes his attention between the cockpit instruments and the external visual world. He may use the airspeed indicator for velocity information, or may judge velocity by direct observation of the ground. Sometimes he uses the real horizon for roll information, sometimes the gyro-horizon. Which is the best source will depend upon the weather, the flight task, and the particular maneuver being conducted at that moment in time. The pilot also must include his emergency instruments in his scan pattern. A warning may come from a dial reading or a warning light or it may be sensed directly. For example, a hydraulic system failure may be detected by noticing the warning light; or, especially if the aircraft is engaged in a maneuver, by an increase in the "stick" forces.

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Only by proper time-sharing can a pilot successfully fly his aircraft. The trainer must teach time-sharing between these sensory cues, as well as the perceptual motor skill itself.

In the sections which follow we shall discuss some of the specific cues the pilot uses during selected critical flight tasks.

### B. ANALYSIS OF THE PILOT'S INFORMATION REQUIREMENTS WHILE PERFORMING VARIOUS FLIGHT TASKS

1. DESCRIPTION AND REASONS FOR THE APPROACH TAKEN. The approach taken here is based in part on that of Calvert (3). Essentially, it involves the laws of geometrical perspective in the control of a vehicle which is free to move in three dimensions instead of two.

One value of this approach lies in its generality. The pilot's task, when reduced to its mathematical essence, is the same for all flight tasks. It may seem strange to state that landing and inflight fueling are the same; but the same information is needed--only the source differs. For example, the pilot must have roll information. This can be provided by the horizon, as it is on landing; or it can be provided by the wings of the tanker aircraft, as is the case in inflight fueling.

Another value of this approach is its simplicity. The enumeration of all possible visual cues would be too long and too disorganized to be of value. For example, there are over a dozen cues for depth. The value of each one as a depth cue is ill-defined, and how they interact remains even more of a mystery. Of course, these complex cues must be considered, but only those which the geometrical analysis has proven to be vital. These will be treated separately with each flight task.

2. INFORMATION REQUIRED TO APPROACH AND HOLD A GIVEN FLIGHT PATH.

a. The Flight Path as the Intersection of Two Planes. The basic task of the pilot performing a visual reference maneuver is to reach a desired flight path. This path may be regarded as the intersection of two planes. One--the vertical plane--moves about an axis which is perpendicular to the earth's surface. The other--the horizontal plane--moves about an axis which is horizontal to the earth's surface. Note that this rotation means that the horizontal plane is not necessarily parallel to the ground plane.

To take an example, during an approach the pilot must hold to a vertical plane through the center line of the runway and to a horizontal plane through the glide slope. This is shown in Figure 1. The pilot faces the identical

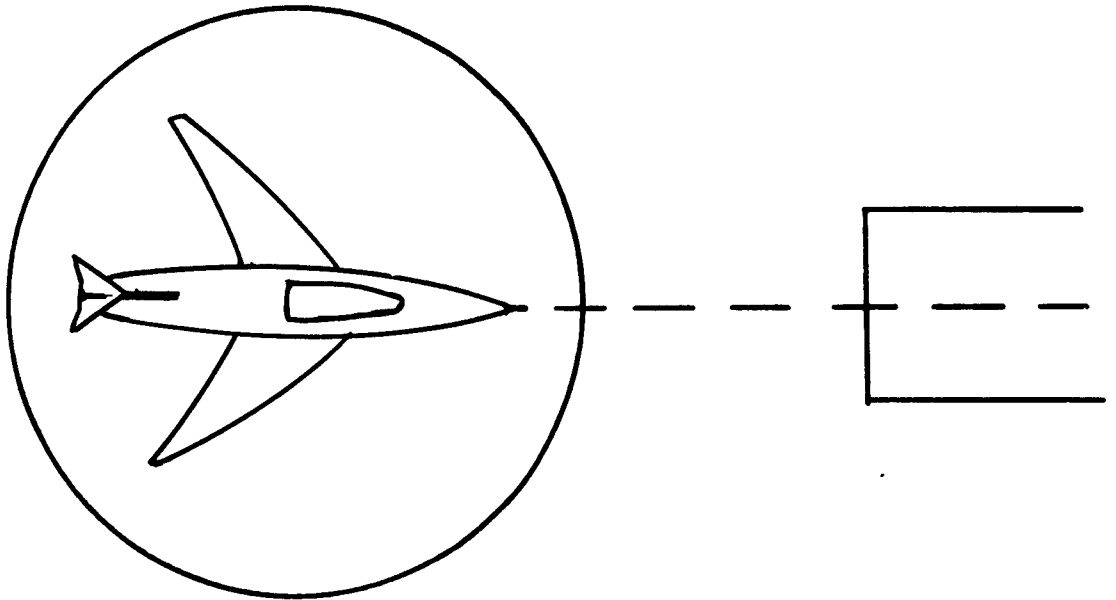


Figure 1a. Aircraft holding to a horizontal plane through the glide slope

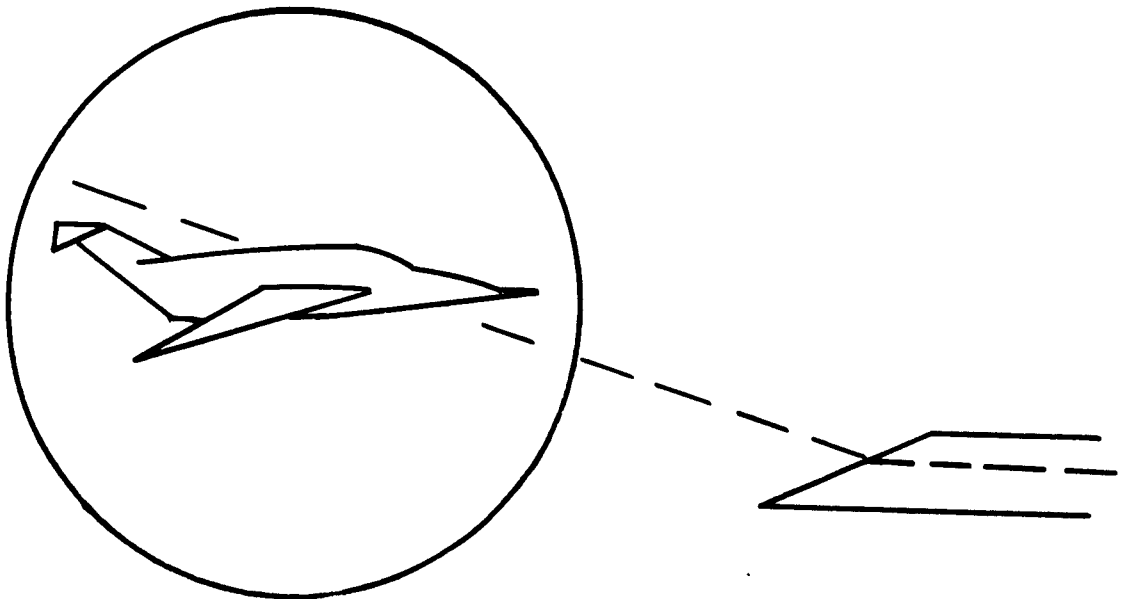


Figure 1b. Aircraft holding to a vertical plane through the center line of the runway

problem, i. e., reach and hold to two planes, in each of his other flight tasks, although, for example, in inflight fueling, the cues available are different and fewer.

b. Displacement, Velocity, and Acceleration to Closure with a Given Plane. The pilot, in order to close on a given plane and hold it, must know his displacement from the plane, his velocity toward the plane, and his acceleration toward the plane. When he reaches the plane, the displacement, the velocity, and the acceleration toward the plane must be zero. Figure 2 illustrates what happens when these three variables do not reach zero, and also what happens when they do. The vertical lines may be viewed as the center line of a runway, the ground plane, the glide slope, or the flight path of a tanker aircraft.

During approach and landing the pilot must hold to a horizontal plane through the glide slope and a vertical plane through the center line of the runway. When the pilot flares out, he must continuously adjust his displacement, velocity, and acceleration as they relate to the ground plane while reducing the rate of his descent. If there is a crosswind, he must continuously adjust these three quantities with respect to the vertical plane as well.

3. THE EFFECT OF HEIGHT ON THE PERCEIVED LATERAL DISPLACEMENT FROM THE DESIRED VERTICAL PLANE. In order to estimate the three quantities--displacement, velocity, and acceleration--the pilot must properly interpret his visual world. Certain illusions based on the laws of perspective and caused by the freedom to move in the three dimensions that the aircraft possesses, will be considered next.

If a pilot does not know his height, then he cannot know his lateral separation from an object. The relation between the threshold of an aircraft carrier deck, the nose of the aircraft, and the pilot's eye is constant. (See Figure 3). If he knows his height and attitude, he knows his distance from the carrier. If he misjudges his altitude, he will err in his estimation of his lateral distance to the carrier. For example, if he thinks he is lower than he really is, he will perceive himself as being closer to the carrier.

Let us now consider the more complex case in which the pilot must determine his closure to a vertical plane. This occurs whenever he wishes to intersect the center line approach lights. Assume that he is in wings-level flight, but displaced from the vertical plane (i. e., an imaginary vertical plane erected upon the center line approach lights). Then, the amount of apparent displacement depends not only on his real displacement, but also on his height above the ground: the greater the

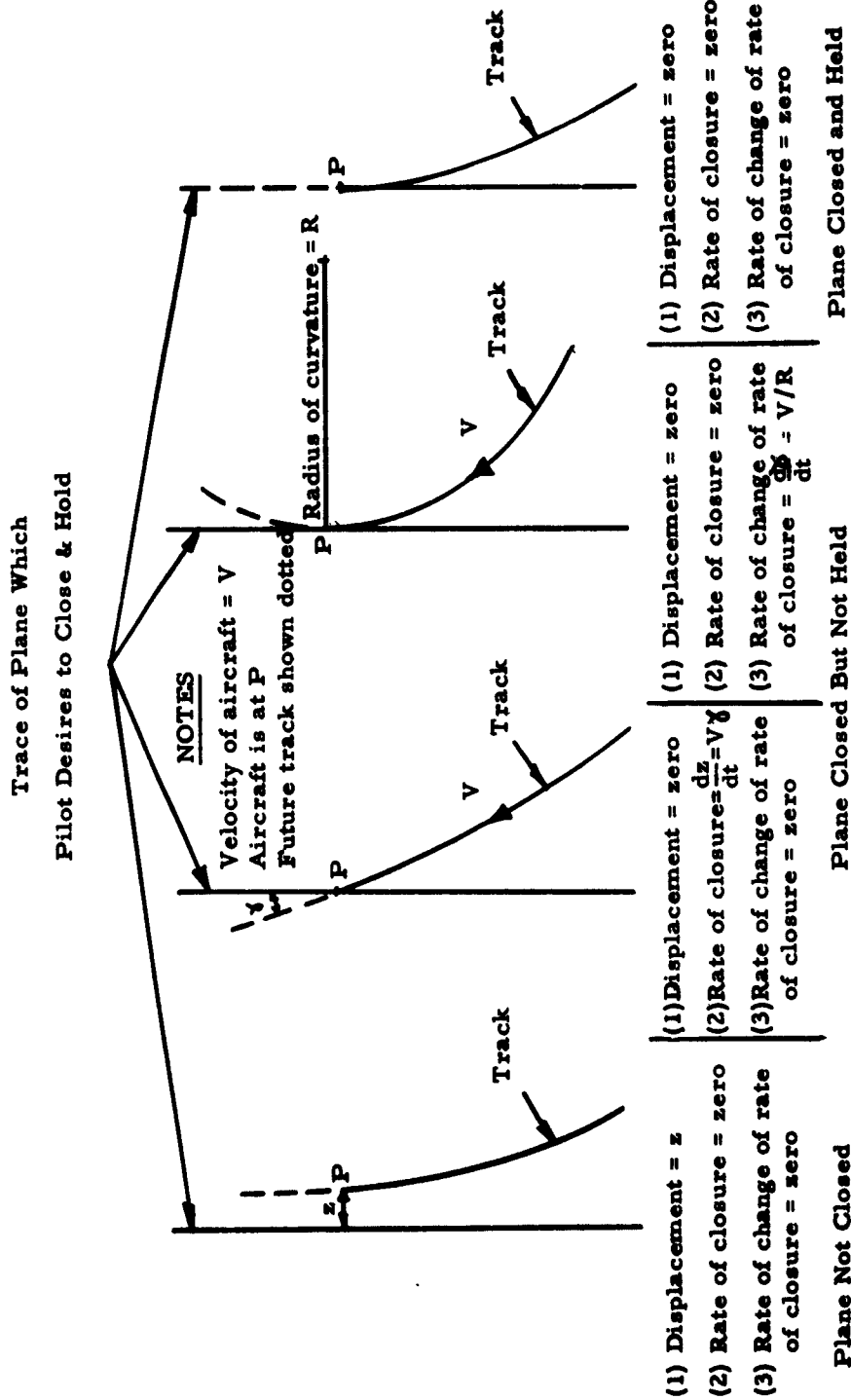
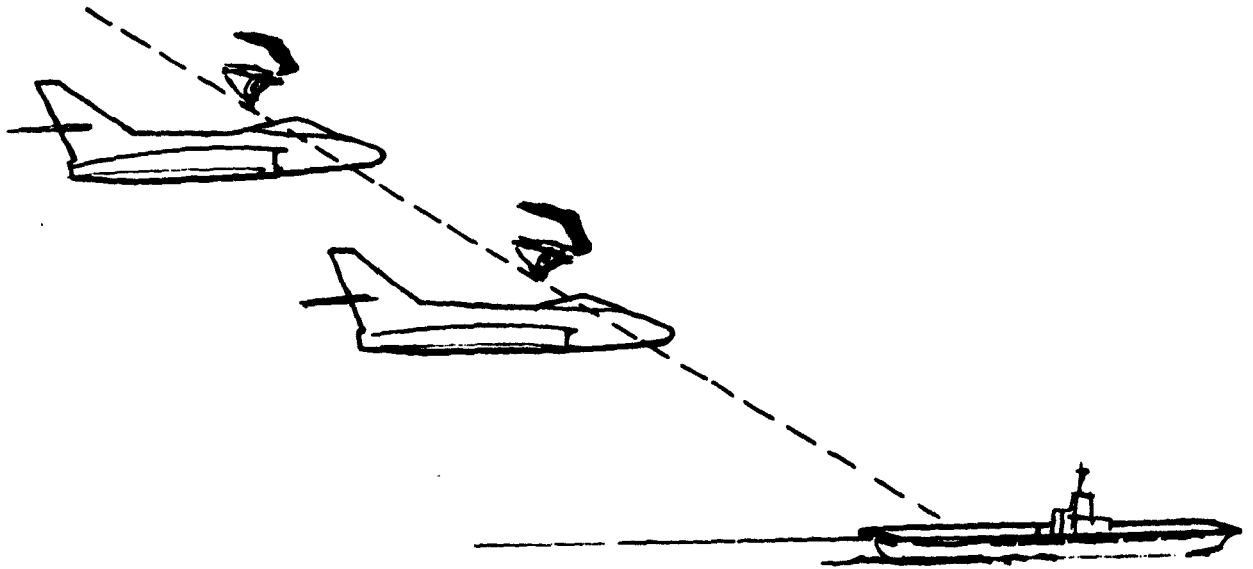


Figure 2. The three conditions which must be simultaneously satisfied in order to close and hold a desired plane (from Calvert, 3)

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**Figure 3. An illustration of constancy of perspective where anywhere along the line the pilot gets the same perspective view.**



height, the smaller the apparent displacement for a given real displacement. This relation can be expressed by the formula

$$\tan \theta = \frac{\text{lateral displacement}}{\text{height}}$$

where the apparent lateral displacement (also called "perspective angle") increases as a function of real lateral displacement and decreases as a function of altitude. Fig. 4 (p. 17) shows this relationship in graphic form. Here the line AB represents the approach lights upon which the desired vertical plane is erected.\* The line AB will continue to become still less perpendicular to the horizon as he descends. Finally, if he is unfortunate enough to land short of the runway, the line AB will appear parallel to the horizon.

In summary, when the pilot is laterally displaced from the desired flight path, he must know his height as well as his lateral separation from the desired plane in order to correctly perceive his displacement, velocity, and acceleration with respect to the plane.

Thus, the perceptual cues for height, such as the perceived size of known objects on the ground, become essential cues for estimating lateral separation. For close ranges, as in inflight fueling, stereoscopic cues (i.e., those enabling the pilot to see three-dimensionally) play an important role in resolving the confusion between height and lateral displacement.

4. THE EFFECT OF ROLL ON THE PERCEIVED LATERAL DISPLACEMENT FROM THE DESIRED VERTICAL PLANE. We have just discussed the difficulty of telling how much of an apparent lateral displacement from a desired plane is due to height, and how much is due to actual lateral displacement. This problem arises even when the aircraft is flying straight and level with the horizon. Now let us consider a separate problem, namely the effect of roll rather than height on the "picture" of the visual world which the pilot sees.

For example, on the downwind leg of an approach pattern to a carrier, the pilot knows that for a specified height the gap between his wing tip and the flight deck informs him of his lateral separation from the flight deck. This gap yields separation information only if he is in straight and level flight. If the aircraft is banked so that the "inboard" wing is slightly low, thus increasing the gap between the wing and ship, and the pilot is unaware of it, he will erroneously assume that his lateral distance from the carrier is greater than it actually is.

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\* The approach lights are assumed to extend from the left side of the runway in the diagrams to exaggerate the perspective angle.

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Roll affects the landing situation in a similar, although much more complex way. This is shown in Figure 5.

If the pilot sees the runway configuration depicted in View (a) of Figure 6 on "breakout" (where there is no horizon visible to provide roll information), then he could be either too far to the left of the center line with wings straight and level, or he could be too far to the right with the wings in a left bank. A pilot who is banked left and displaced to the right of the runway, but who assumes that he is straight and level will perceive himself to be to the left of the center line, when actually he is to the right of it. A right turn where a left turn is called for can be fatal. The situation is clarified in Figure 6: (a) is what the pilot sees; (b) and (c) indicate his lateral displacement and amount of bank.

This situation can be analyzed geometrically. If the picture which the pilot sees is as in Figure 4, and he then rolls his aircraft into a bank of angle A right wing down, the outer world will appear to roll counter-clockwise through the same angle, and the picture will change to Figure 5. If instead of rolling, he had reduced his lateral displacement and/or increased his height, the line AB would have rotated in the identical fashion relative to the framework of the aircraft, but the horizon would not. Thus, when the horizon is not visible, the pilot cannot distinguish lateral displacement from roll. Two other cues for roll are gyro-horizon and bodily cues, but the pilot may not have time to consult the first and the second is notoriously unreliable.

Let us at this juncture demonstrate how this type of analysis can be used to make design recommendations for visual displays. The type of pilot error just discussed is one which flight simulators should teach; if they fail to do so, the trainee may never encounter the condition where he might confuse situations (b) and (c) of Figure 6. This confusion does not arise in the P3/Dalto landing simulator itself as now designed, because it cannot roll. Since it cannot roll, View (a) is always interpreted as View (b) because the pilot is always aware where the horizon is or should be. Clearly, a trainer equipped with a nonprogrammed visual display is deficient if it fails to simulate one of the most dangerous illusions a pilot can encounter. The appropriate recommendation here, then, is that the cockpit of the flight trainer itself be given some roll.

5. **GEOMETRICAL ANALYSIS OF THE TEMPORAL PERSPECTIVE SHIFTS WHICH PROVIDE CUES FOR VELOCITY AND ACCELERATION.** We have seen what the displacement cues are; now we can investigate the rate cues. The pilot must know how fast he is closing to a desired plane as well as his location. The cue for velocity is the expansion pattern. The closer a moving observer is to an object the faster it appears

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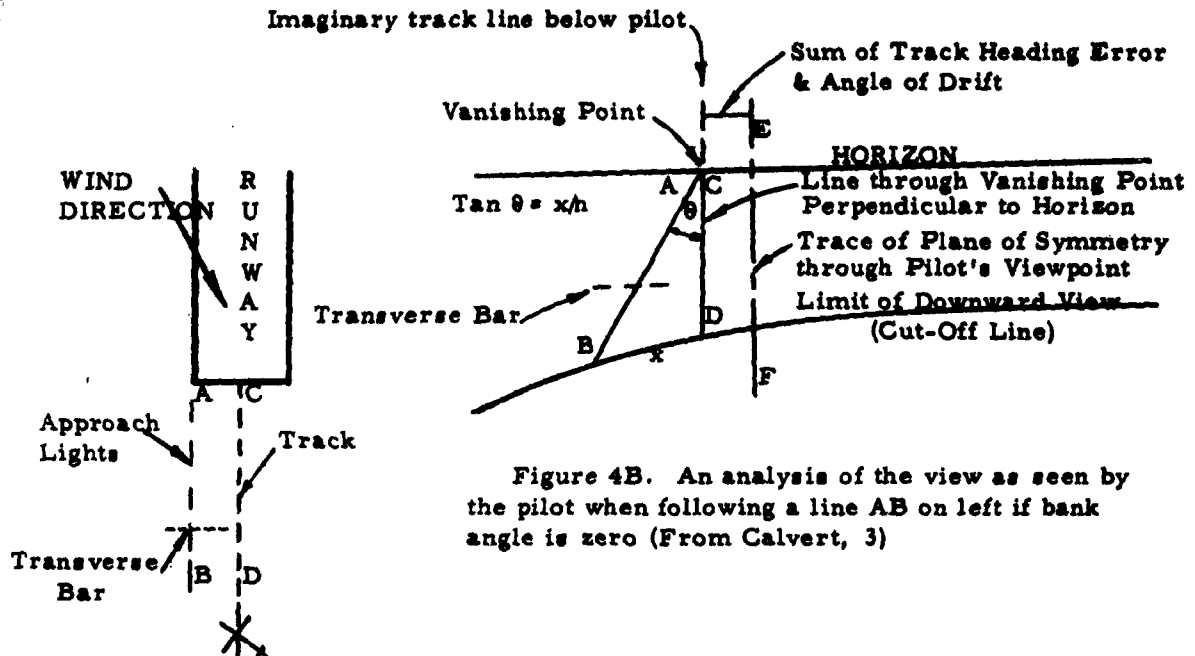
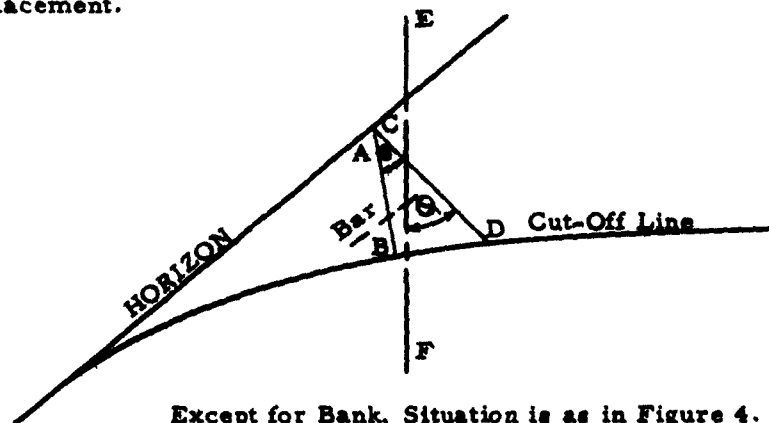


Figure 4B. An analysis of the view as seen by the pilot when following a line AB on left if bank angle is zero (From Calvert, 3)

Figure 4A. An aerial view of the approach situation to be used in conjunction with the interpretation of Figure 4B

CD is the image of a line on the ground which represents the track of the aircraft. AB represents the approach lights extending from the left of the runway. The pilot is making an approach to the runway and is at present at height  $h$  (not shown on diagram) looking at line AB on the ground at a distance  $x$  to his left. Although CD and AB are actually parallel (Fig. 4A), they will not appear so to the pilot (Fig. 4B). Angle  $\theta$  is the perspective angle. The line AB will appear to rotate with changes in height as well as changes in lateral displacement.



Except for Bank, Situation is as in Figure 4.

Figure 5. View seen by pilot when following a line AB on left if bank angle is  $\theta$  with right wing down (from Calvert, 3)



- (a) The view as seen by the pilot on breakout during an instrument approach for landing without a horizon when his A/C is slightly to the left or to the right as clarified in (b) & (c)



- (b) The view as seen by the pilot on breakout during an instrument approach for landing if the horizon were to suddenly appear with the A/C to left of runway with wings level



- (c) The view as seen by the pilot on breakout during an instrument approach for landing if the horizon were to suddenly appear with the A/C to right of runway and banked to the left

Figure 6. The ambiguity of position with respect to runway based on perspective information when the horizon is absent

to move toward him. The reason is simple: the pilot decreases his distance from a near object by a greater proportion during one second of travel than he decreases the proportionate distance from a far object. Consider Figure 7. In moving from  $T_1$  to  $T_2$ , he has halved the distance from object A, and object A has doubled its size on his retina. However, at the same time, his distance from B has decreased only from 400 yards to 300 yards and the image on his retina has expanded by only one and one-third. This simple expansion applies only to the spot in the visual field at which the aircraft and the pilot's gaze are directly pointed. The parts of the visual field at which the aircraft is not directly pointed expand at rates which are determined by the laws of perspective.

We may now examine the complex case. The X-point is the point at which the aircraft is aimed at each instant. It is the point of no apparent movement; an object there does not tend to move out of the field. The area surrounding the X-point appears to move away from it out of the field of vision at a rate which is a function of the aircraft's velocity toward, and distance from, the X-point. The X-point must be within an appropriate range depending upon the point in the approach which the pilot has reached at that moment. For example, the X-point will keep swinging around the runway as the pilot makes a  $180^\circ$  turn. This situation provides the information which gives him his rate of approach and acceleration toward the desired plane. The distance between the X-point and the horizon informs the pilot of the angle at which he is approaching the terrain. It is directly below him as he dives directly toward the earth; and swings from there to the horizon as he pulls out of his dive to fly parallel to the ground plane.

The way in which the pilot finds this point is illustrated in Figure 8. As the aircraft approaches, the X-point moves from  $X_1$  to  $X_2$ , and each point on the runway has moved from the arrow to the point marked by the arrow head.

The picture which the pilot of an aircraft proceeding along the track would see if he looked along the center line at the horizon is shown in Figure 8. All objects in his field of view appear to him to move along paths (called "streamers" by Calvert) which have the property that at any moment their tangents meet at the point towards which the aircraft is proceeding at that moment, i. e., the X-point. The angular distance of X below the horizon gives him his rate of closure with the ground, and the angular distance of X from the vanishing point, V, measured along the horizon, gives him his rate of closure with the vertical plane through the center line. The movement of X perpendicular to and parallel with the horizon, gives him his rate-rate (acceleration) in the vertical and horizontal planes respectively.

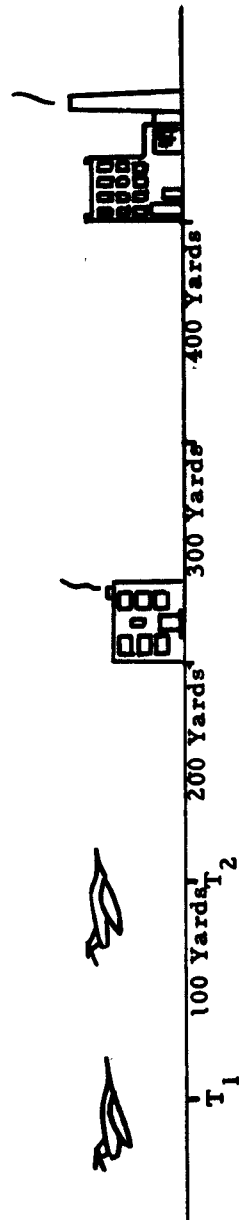


Figure 7. Illustration of how temporal perspective shifts provide cues for velocity and acceleration

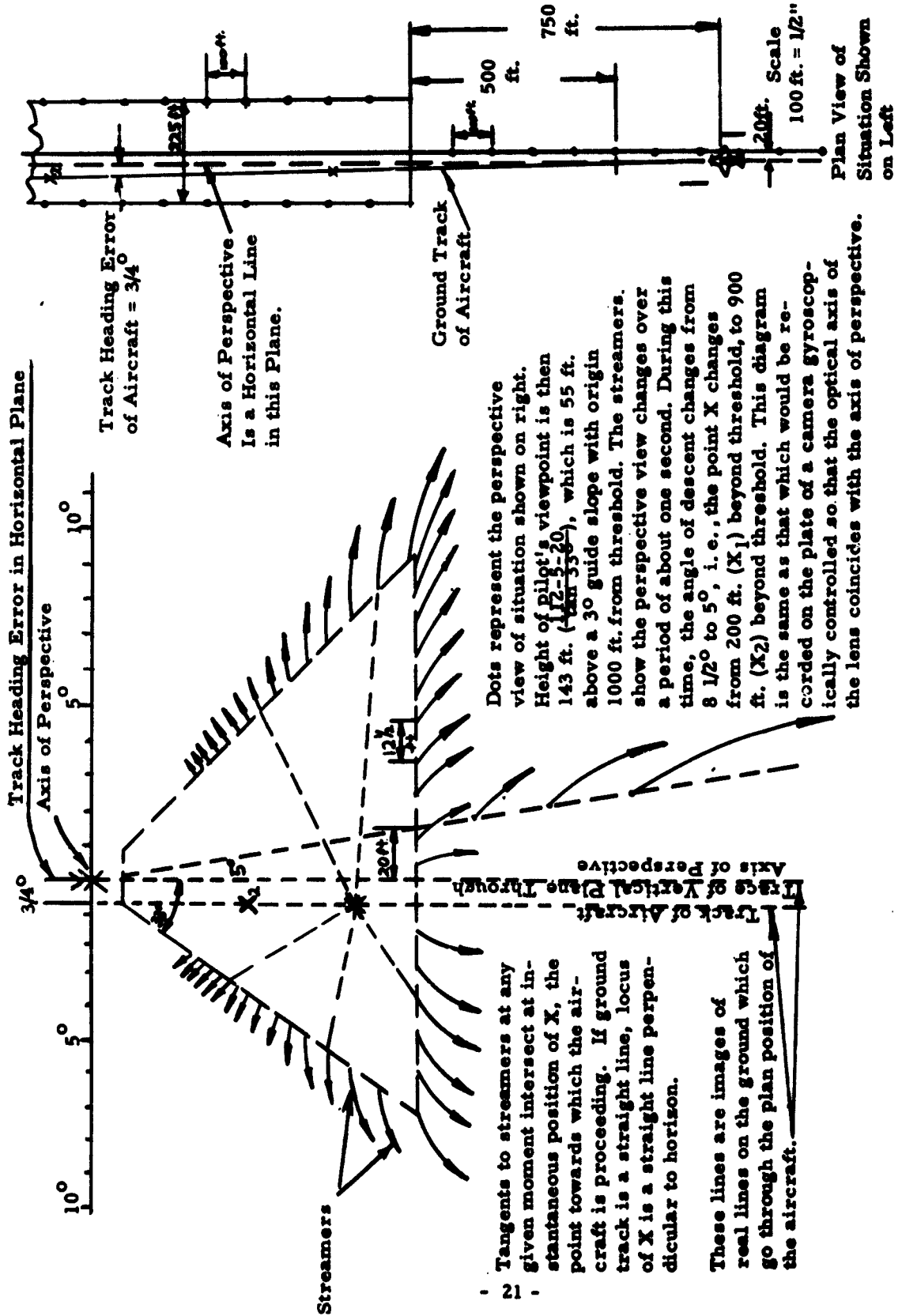


Figure 8. View of runway showing how pilot obtains rate information while landing (from Calvert, 3)

The streamers shown in Figure 8 are similar to those on the retina of the pilot's eye only so long as he looks along the center line in a fixed direction in space. This is why pilots stare straight ahead during the final portion of the approach, and during the landing. Distractions of any kind which cause him to move his eyeballs or head will therefore reduce the accuracy of these judgments. Another factor which will affect the accuracy of these judgments is the nature of the terrain in the approach area and the presence or absence of markings on the runway.

The streamer velocity in the visual field at any given angular distance below the horizon is inversely proportional to the altitude of the aircraft, assuming the velocity of the aircraft to be constant. It follows that without definite objects in the foreground, the pilot will have poor height guidance as well as poor rate guidance. This explains why it is so difficult to make accurate approaches over the sea, or over featureless desert or snowfields, and why clearing the approach areas may increase the probability of undershooting. It is interesting to note here that the pilot approaching a drogue in the fueling task gets his cues for velocity and acceleration through a visual scan pattern which is quite different from that used in landing. In daytime landings, velocity and acceleration cues come from the richly textured terrain outside the cockpit; in inflight fueling these cues are missing in the textureless sky, and the pilot consults his airspeed indicator to obtain closure rate information with respect to the drogue. Thus, although the pilot has the same broad task, i. e. , to maintain and hold his position with respect to the intersection of two planes, the attention-sharing and the visual scan pattern are completely different, because of the difference in the cues available.

6. **ORIENTATION CUES: PITCH, ROLL AND YAW.** Although much of the pitch, roll and yaw information a pilot obtains has been covered earlier, there are a few additional points to emphasize because of their implications for the analysis of the pilot's task in flying various visual reference maneuvers.

Information about the pitch of an aircraft is given by the nose-to-horizon distance. Since the horizon remains at infinity, this distance is constant for any pitch angle. This, of course, is not true for certain horizon surrogates such as the horizon bar positioned under the mirror in the mirror landing system. The bar gives adequate roll information, but inadequate pitch information, since the bar-to-nose distance will continually shift as the aircraft approaches the landing aid.

Information about roll is perceived by the angle between the base of the windshield and the horizon, or, more peripherally, by the distance



between either wingtip and the horizon. Information about yaw is more difficult to perceive; it is the distance or angle between the point at which the flight path is directed (as determined by the X-point) and the point at which the aircraft is actually pointed.

C. ANALYSIS OF THE VARIOUS FLIGHT TASKS (APPROACHING THE GROUND PLANE, AND APPROACHING AND HOLDING AN INFLIGHT OBJECT)

1. THE PILOT'S TASK TREATED AS A WHOLE. Now we would like to examine the pilot's task as a whole in order that the visual reference maneuver may be properly shown in its total context.

The pilot and nonpilot behavior to be studied in the flight trainer must be related to--must in fact be segments of--the behavior of a pilot flying an actual aircraft. Examination of the pilot's activity shows that he has four major tasks to perform while flying an aircraft. He must:

(a) Preserve the aerodynamic stability of the aircraft by (1) viewing the external visual world, and (2) by regarding the flight instruments: altimeter, directional gyro, gyro-horizon, airspeed indicator, needle-ball, rate-of-climb indicator, and accelerometer.

(b) Guard the physical and operational integrity of the aircraft by (1) avoiding collisions with intruding aircraft, (2) spotting cockpit emergency indications, and (3) monitoring the secondary instruments such as fuel supply.

(c) Control the direction of the aircraft on both a long term basis, namely navigation, and a short term basis, namely the visual reference maneuvers of landing, inflight fueling, formation flying, etc.

(d) In addition to performing each sub-task well, the pilot must integrate these tasks; thus, he must develop proper time-sharing techniques, so that his eyes never depart for long from any part of the visual world.

(1) Importance of Time-Sharing. While the primary emphasis of this report is on the external visual world as the pilot's information source, we must not lose sight of the fact that other sources of information are provided by a scan pattern, whereby the pilot continually glances from one area of the visual field to another and from one instrument to another. What is the best scan pattern is a function of the particular task being done. It may range from 95% of the glances inside the cockpit on the initial part of an ILS approach to 100% outside of the cockpit during the final moments just before touchdown. The teaching of a proper scan pattern--one in which the pilot views the appropriate part of the visual field at the right moment--is

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just as an important part of simulator training as is the teaching of the perceptual motor skill itself. Training on what is most likely to happen next--expectations--teaches the pilot where to anticipate the need for future scan patterns. The skilled pilot shifts direction of the attention and gaze in accordance with an operational plan. Besides developing proper time-sharing habits suited for each task, the pilot must be trained to avoid the mistake of stimulus fixation--staring for a longer period of time than is required to assimilate the necessary information. This happens where the pilot fixates on an instrument that is awry; for example, he may be so busy getting his rate-of-descent indicator back to zero that he fails to notice that the aircraft is in a sharp bank. Or, to take another example, on breaking out of the clouds on an ILS approach, the pilot may fixate on the approach lights, instead of maintaining a scan pattern which includes the instruments as well as the field lights. Failure to scan back and forth means that the pilot would have a difficult job of controlling the aircraft if he had to transition back to instruments should the fog suddenly close in again.

A flight trainer which fails to develop the proper time-sharing of attention in the trainee may well be worse than no trainer at all, regardless of how realistic the visual display is. The goal of a trainer is not merely to develop great skill in even critical subtasks, but to develop sequential scan patterns which will yield the greatest amount of vital information in the quickest and most secure manner.

Some examples will clarify this. Should the pilot consult his gyro-horizon or should he consult the natural horizon for roll information? Should he use his airspeed indicator or the streamer pattern for velocity information? The answer will depend upon the particular flight sub-task involved, the precision of the information required, the feasibility of removing one's gaze from the outside visual world when close to other objects, the ability of the nonvisual senses to substitute for visual information, and the adequacy with which the external visual world provides the required information.

Some of these points will be discussed using examples from the landing task.

(2) Particular Flight Task Involved. The pilot uses different scanning techniques even when tasks as similar as landing and takeoff are involved. Fortunately, definite data are available concerning these tasks.

Edwards and Howell (7), using a motion picture technique, found that areas on the windshield that show high usage are those through which the pilot is obtaining visual cues from the terrain necessary to control the aircraft, and not areas which are used to search for other aircraft. During takeoff the pilot scans directly ahead in a horizontal sector covering sixty degrees of angle, and in a vertical sector covering zero to five degrees

above the horizon. During descent, the horizon and an area to the lower right are scanned. During final approach he fixates just above the horizon and five degrees to the right. Besides knowing where the pilot looks, we must know how long he looks. Milton, et al. (2) found that during the first half of visual contact takeoff, 81 per cent of the time was spent looking outside the aircraft, and during the second half only 37 per cent of the time was spent looking outside; but while landing, 73 per cent of the time is spent looking outside the aircraft instead of at the instruments.

In terms of the global task encountered by the pilot, many sub-tasks such as avoiding aircraft and monitoring emergency indicators are not taught in the Dalto simulators. The trainee, safe from intruding aircraft as well as own aircraft emergencies, develops bad habits in the form of inappropriate time-sharing and emergency-expectancy patterns.

(3) Precision of the Information Required. Generally, the most precise information is obtained from the flight instruments such as the air-speed indicator. This is particularly true when distance, or atmospheric conditions, make the terrain cues inadequate. However, when he is close to the textured surface of the earth, external visual cues as well as auditory and proprioceptive cues will give him most of the rate information he needs. We saw earlier (p. 22, paragraph 1) that to get this rate information he must stare fixedly ahead.

(4) Summary. The flight simulator with an external visual display offers an opportunity to practice those aspects of flight requiring external visual cues as well as visual cues from the cockpit instruments; and more important, the sharing of attention between these two visual worlds, the external visual world and the within-cockpit visual world.

2. THE ANALYSIS OF SPECIFIC FLIGHT TASKS. In the past, most of the emphasis in visual training device design has been placed on the flight task of landing. The large proportion of existing devices devoted to the landing situation is also reflected in the amount of literature devoted to analyzing the visual cues employed by the pilot in executing the landing flight task. This attention is certainly justified in terms of the time devoted to training pilots in the landing phase of flight, and in terms of the consequences of unsuccessful performance of the landing task. The landing phase of flight has long been the source of the majority of aircraft accidents which occur. Consequently, we have chosen to emphasize this flight task for a perceptual analysis. Such analyses are an essential first step in determining the extent to which existing visual attachments are capable of fulfilling the flight task training requirements in which supplemental visual inputs play a critical role.

However, there are many other tasks in the flight situation that are heavily dependent on visual inputs to the pilot, and which require skilled

visual discriminations. Although no attempt will be made to exhaust all of these visually augmented phases of flight, we have analyzed in detail a sample of flight tasks for which specific training problems have been identified. These tasks are Formation Flight, Inflight Fueling and Air-Ground Weapons Delivery. These part-tasks were chosen because the visual component is an important one; they are difficult to perform; they take a long time to learn; and they are hazardous to execute. It is important to lower both the accident rate and the training time in these areas.

In the next section each of the flight tasks we have chosen will be analyzed in terms of the perceptual cues available to the pilot to aid him in the performance of his task. Following this perceptual analysis, a functional analysis of the selected flight tasks of approaching and holding an inflight object will be made.

### 3. FLIGHT TASK: APPROACHING THE GROUND PLANE (FIELD LANDINGS AND AIR-GROUND WEAPONS DELIVERY)

a. Description of the Flight Sub-Tasks. Lane and Cumming (18) point out that errors in location of touchdown point during landing constitute the largest single safety problem. Zeller (33) reporting on undershoot and overshoot accidents, holds that the primary cause is faulty distance and rate-of-closure judgments on the part of the pilots. Experienced pilots were less apt to make an error.

Since field landings and many types of air-ground weapons delivery involve many of the same perceptual cues, particularly an extensive well-textured terrain, they will be analyzed together. Where differences occur, they will be pointed out.

Here the pilot approaches and holds a particular flight path, which in the vertical plane is the runway approach path (field landing), or the weapons delivery run at the target (air-ground weapons delivery); and which in the horizontal plane is the glide slope path (this may be shallow or steep depending on the nature of the task).

The flight task of the pilot may be divided into a number of sub-tasks;

- (1) detect the presence of a possible airstrip or target;
- (2) identify the airstrip or target as the desired one;
- (3) close to and hold the desired flight path in the vertical and horizontal planes; and

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- (4) touch the airstrip or release the weapon when displacement, velocity, and acceleration with respect to the two planes are at their proper values. In the case of landing, the proper value is zero for all six variables: displacement, velocity, and acceleration toward each of the two planes.

An excellent analysis of the visual information requirements for landing has been made by Lybrand, et al. (19). We should like to refer the reader to this work for greater detail. The airspeed, altitude, distance and position from the landing point, and lateral freedom in the flight path define the "flight tunnel." Since the volume of space available to the pilot decreases at touchdown, "flight funnel" is a more descriptive term. In order to get into position to final approach, the pilot must check: (1) his relationship with the runway (the proper position will vary with the wind condition); (2) the altitude of the aircraft with respect to the earth's surface; (3) the position of pitch and roll axis relative to the earth's surface; and (4) the yaw axis relative to line of flight. The velocities and accelerations with which these positions are changing also must be known.

Instruments and cues of pressure and sound are useful in determining the performance of the aircraft, but the main cue is provided by vision outside the aircraft. For example, at a particular altitude on the downwind leg, the wingtip should appear to be a particular distance from the runway. To correctly position his aircraft, the pilot uses judged distances (wingtip-to-horizon, nose-to-horizon) as well as judged angles (wingtip-along-horizon, angle between canopy strut and horizon), or other known ground references.

The position of the X-point (the point at which the aircraft is aimed) is a difficult perceptual judgment, especially at any great distance from the terrain. Roll and pitch information are discriminations rather than judgments; i. e., they are immediately apparent as long as the horizon is visible. (See Bartley, 2)

The difference between a discrimination and a judgment is an important one. If the pilot can get the same information from a discrimination as he can from a judgment, he should be taught to use the discrimination--it is much quicker.

How does the pilot find visual reference objects, and once found how does he utilize them? A scan pattern serves to put the eye into position to detect the presence of objects in order that visual reference maneuvers may be flown.

Although the length of time it takes for detection, discrimination, identification, or judgment may vary from function to function, these are listed below in order of time required for their accomplishment. The first task

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can be done in one tenth of a second; the fourth could take three seconds or more.

(1) Detection. Here the pilot merely becomes aware that something is amiss. The emergency may be in the form of an intruding aircraft, or an aircraft malfunction indicated by a light on a cockpit panel.

(2) Discrimination. Here the pilot makes a quantitative judgment about something which is clearly visible in the visual field, for example, the angle between a canopy strut and the horizon. The percept is immediate, not requiring an analysis of the situation.

(3) Identification. The pilot judges which object, in the absolute sense, is present. There is no comparison stimulus present in his visual field; he decides, for example, that the approaching aircraft is a DC-3.

(4) Judgment. The pilot is required to interpret the operational significance of intruding aircraft and/or instrument readings in the context of the flight situation. Judgments are complex and require more time than do discriminations. For example, the interpretation of an oil gauge reading during a particular flight regime as indicating an actual or impending emergency would be a judgment. The determination as to whether an intruder aircraft is on a collision course would be another instance of a judgment.

b. Perceptual Information Sources from the External Visual World for Flying Selected Critical Sub-tasks. Here we will analyze the perceptual cues available to the pilot, state whether or not they are adequately simulated in the nonprogrammed visual display attached to flight trainers, and make recommendations concerning visual displays referring to the landing flight task.

### DISTANCE OR DEPTH

(1) Binocular Cues. The major binocular cue is that provided by the disparity between retinal images. That is, the retinal images are slightly different, the image of the right eye being like a photograph taken slightly to the right side of the object; and the image of the left eye being like a photograph from the left side. These two images are fused in the brain with the resultant perception of depth. The binocular cues are useful up to a distance of between 490 and 700 yards, according to Diamond (5).

The number of successful one-eyed pilots attests to the fact that in the landing task, where the pilot is surrounded by an overabundance of monocular cues for depth, the binocular depth cues are not essential. This effect is obvious: if we close one eye in a richly textured environment, everything seems to be just as far away; depth perception does not change.

For simulation of the landing task it is not necessary that the trainee be presented with a stereoscopic visual display, provided that there are a large enough number of monocular depth cues. This provision is not always met. The Dalto display--a projected image on a flat screen--does not elicit a very realistic experience of depth.

(2) Monocular Cues.

(2.1) Linear Perspective. This is the well known cue provided by runway lights or edges which are actually parallel, but appear to converge in the distance. These laws of perspective have been discussed; the higher the pilot is approaching the runway the less converged (more parallel) will the edges of the runway appear to him. Linear perspective thus serves as a cue for altitude as well as distance. This cue is very well duplicated in landing simulators such as the Dalto.

(2.2) Texture Compression. This term has been used by Gibson (12) to describe "linear perspective" when there are no lines stretching to infinity present in the visual environment, but only random texture, such as that provided by forests, irregular fields, skid marks on the runway, etc. The depth cue provided by texture compression is less apparent to the aviator than is that of linear perspective, but it is usually the only one present except when he is landing on a field equipped with runways.

Most simulated runways are too "clean," and lack cues of texture compression. Skid marks, cracked pavement, earth scars should be added. While TV displays generally lack sufficient resolution to provide many of these finer textured details, these types of cues can be added.

(2.3) Shape. This is simply the laws of linear perspective applied to enclosed figures. The shapes of buildings, runways at a distance, etc., vary with position of view. Shape of the landing strip tells the pilot where he is; the more directly above the strip he is, the more rectangular the strip will appear. Figure 9 shows perspective of runways for pilots who are too high or too low.

Related to shape is the notion of symmetry. Figure 10 illustrates this point.

The Dalto lacks any clearly enclosed figures such as buildings. This may be one of the reasons that altitude judgments are hard to make in this device. The runway lights, however, probably compensate for this loss.

(2.4) Interposition. Interposition simply means the superimposition of near objects on far objects. It is a good cue for distance; i. e., if an object is partially hidden by another object, the hidden object obviously must be behind. Interposition in relation to the horizon is a very important

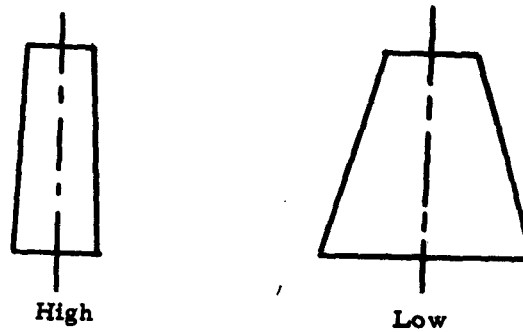


Figure 9. Perspective and size of runways for pilots who are high or low

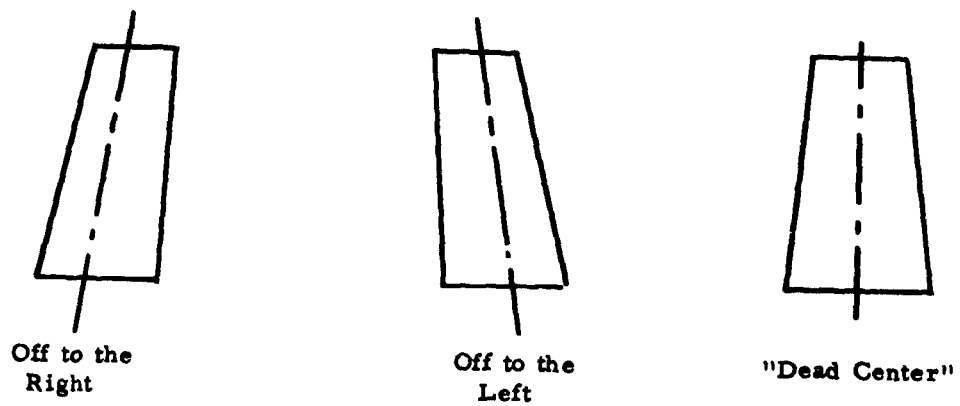


Figure 10. Various runway shapes as a function of position of the pilot in space in relation to the runway



cue for height of the aircraft; if a tree top or telephone pole intersects or rises above the horizon, then you are at the same altitude or below the object. Similarly a roof of a flat building will disappear behind its wall once you are below roof level. (The principle of interposition is used in the POMOLA guide path indicator display.) This important cue for altitude and distance is lacking in most nonprogrammed visual displays.

(2.5) Size of Familiar Objects. The apparent size of objects of known size provides a cue for distance, since the retinal image of an object varies inversely with the distance. Thus, if the pilot is familiar with the runway size, he is aided in estimating its distance.

It has been reported that pilots who have over-practiced on a wide runway will land hard when they are first switched to a narrow runway. This occurs because the narrow runway, when they are very close to it, gives the same appearance as the wide runway from a higher altitude. The pilots naturally assume that they are at this higher altitude on the basis of past experience.

Some nonprogrammed visual displays are equipped with only one width of runway. If this is not equivalent to the width of the runway which the pilot uses during actual landings, there is clearly a danger of an under-shoot or overshoot. It is recommended that the trainees be given experience with various widths and lengths of runways in order that they may be able to generalize their responses to a wide assortment of stimuli (runways) in the real world.

(2.6) Perceived Distance Between Object and the Horizon. The visual angle between an object and the horizon increases from zero degrees when the object is distant, to ninety degrees when the pilot is directly over it. The initial sighting of the runway followed by an approach over the runway threshold is an example here. The Dalto visual display, not being equipped with a horizon, fails to provide training in the use of this cue and actually does not require it for the part-task for which it was designed.

(2.7) Motion Parallax or Movement Perspective. As the pilot moves through space, his eye (remember we are considering monocular depth cues) takes up successive positions in space. By successfully integrating these cues from successive positions, the brain gets a picture akin to what it would obtain from binocular vision. Objects are seen slightly from one side and then slightly from the other. Also, close objects appear to glide past in our field of view in the opposite direction to which we are moving; while distant objects appear to remain almost motionless. The apparent velocities are inversely proportional to their real distances away; consequently safe conclusions can be drawn as to the real distance of the object.

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The cue of motion perspective probably provides an important depth and distance cue for one-eyed pilots. Since trainees viewing the image of the runway projected on a flat screen also lack stereoscopic vision, they are utilizing the same cues as are used by one-eyed pilots. Such a projection may then be sufficient for training purposes in the simulator landing task.

(2.8) Resolution of Detail. Related to size, but perceptually distinct, is resolution of detail. No matter how small and far away a runway seems, if you can distinguish detail such as the fine texture of the concrete in a runway, you must be very close. The same applies to the approach lights: from the distance they appear almost as continuous bars, but upon getting closer, you begin to see them as rows of distinct lights.

Television displays appear to lack sufficient resolution to provide any great amount of experience with this cue. The landing lights of the Dalto display consist of reflected light. (They are not scaled to proper size.) Thus, the only way to make them more visible is to make them larger. This size-intensity problem means that the Dalto runway lights are not sufficiently blurred into a bar at a distance--compared to the real situation--and, on the other hand, are too blurred at close distances to be like point light sources.

(2.9) The Relative Brightness of a Point Source. The relative brightness of a surface reflecting light into the eye does not vary with distance; however, the intensity of a point source, such as a runway light very definitely does change with distance.

The runway lights in the Dalto are objects which reflect light. Their brightness does not vary with distance; thus they are too bright when the pilot is distant and too dim when the pilot is close to the runway. Realism could be greatly increased if the very small "grain-of-wheat" lamps were inserted in the runway in lieu of the dots of paint. This action would also solve the problem mentioned above concerning the monocular cue of resolution of detail.

(2.10) The Molding and Shape of Surfaces as Revealed by Shadow Patterns. Hills and valleys are clearly visible from the air at sunrise and sunset. This cue is probably of little use except when landing on very rough terrain. There is no need to duplicate this cue in the landing simulator, but it should be introduced into the weapons delivery trainer.

(2.11) Aerial Perspective. Because of atmospheric attenuation, distant objects lose contrast with their surroundings, i.e., they shift from black on gray, to gray on gray. The object's color becomes less saturated (grayer) and tends toward a purple hue.

Aerial perspective, while of some general help to the aviator orienting himself to distant terrain features, is not needed in landing and probably need not be duplicated in the nonprogrammed visual display.

### VELOCITY AND ACCELERATION

In an earlier section we saw that in addition to knowing his distance from a plane, the pilot must know his velocity and acceleration toward that plane if he is to close and hold it successfully. Rate and rate-rate information comes from the streamer pattern. To estimate angular velocity, one must know the distance of the object as well as being able to successfully judge the speed of the retinal image.

Clearly, these cues are only available in a textured environment. When landing on a snow field or on a glassy sea, one part of the visual field looks like the next; there are no texture elements to go whizzing by.

Gibson (12, 14) has emphasized the importance of the streamer or expansion pattern in landing. The landscape appears to be rushing past or away from the pilot except for the point at which the aircraft will touch ground if it keeps its present course, the X-point. Apparent movement occurs in all directions away from this X-point. The rate is a function of the pilot's speed and his distance from any point on the surface. Gibson, et al. (13) give some pictorial examples of this. The gradient of clarity of the streamer pattern means that different parts of the pattern yield information at different rates. Hochberg and Smith (16) point out that the motion of texture units around the X-point may be too slow to provide useful information, while motion in the periphery may be so fast that the streamer pattern degenerates into an unresolvable blur. Hoffman (17) mentions that tests have shown that a pilot's field of vision during takeoff and landing is highly affected by speed and relative terrain, and that the pilot's field of view narrows to less than 15 degrees of visual angle. (Thus it may not be so vital to have wide angle visual displays after all.) Also, the pilots tend to look fixedly down the runway. These two factors make it difficult to evade other aircraft, but apparently are necessary if the pilot is to utilize the streamer pattern effectively. Gibson (11) found that training helps the location of the point of zero motion, the X-point. Most of the cues for distance become cues for rate as they change in size over time; thus the binocular and monocular cues for distance, the presence of familiar objects, linear perspective, object shape, and interposition are important for judging velocity and acceleration.

Very little research has been done on acceleration or deceleration. Hick (15) found (but this was under favorable laboratory conditions where the observer had an opportunity to practice and know the correct distance) that a velocity increment must be at least 12% before it could be detected.

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It is extremely likely that the best cues for acceleration are not visual at all, but auditory (engine and air speed noises), and vestibular and proprioceptive in origin. It may well be that a motionless trainer leaves out some very significant cues for acceleration.

### ROLL

The major source of roll information is the angle between the horizon, or something parallel to it, such as the runway threshold, and the base of the aircraft's windscreen.

In the real world the airplane swings around the horizon. In the simulator, the horizon swings around the trainer. Since the P3 trainer has no roll there are certain perceptual situations the pilot encounters in the aircraft which the trainee does not get experience in. Consider the problem discussed and illustrated in Figure 6, where the same visual situation confronts the pilot when he is off to the left of the runway and straight and level, as when he is off to the right of the runway and banked to the left.

In order that the pilot may receive training in this vital problem, it is recommended that the trainer have roll capabilities, and that spurious cues for the proper position of the horizon, namely edges of the projection screen on the Dalto display, be eliminated and replaced with the wide field of view afforded by the 151 nonprogrammed visual display.

### PITCH

The horizon also provides immediate pitch information. Since the horizon is always at the same (infinite) distance away, the pilot merely has to keep the nose of the aircraft a constant distance above, on, or below the horizon in order to alter or maintain altitude. Unlike roll information, which can be extracted from objects other than the horizon, pitch information can be gotten only from the horizon. For example, the nose-to-runway threshold distance keeps changing as the aircraft approaches it. While flying straight and level, the nose-to-horizon distance remains constant.

4. **FLIGHT TASK: APPROACHING AND HOLDING AN INFLIGHT OBJECT (FORMATION FLIGHT AND INFLIGHT FUELING).** A functional analysis of formation flight and inflight fueling from the standpoint of the wingman and "tankee" (pilot of the aircraft to be refueled) was undertaken so that the reader might contrast this approach with the cue approach to the landing task.\*

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\* The functional analysis has the advantage of being more easily and directly applied by operational pilots.

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The reason for selecting this frame of reference is that the visual tasks of the formation leader and tanker pilot are relatively simple when compared with the tasks of the wingman and tankee. Since the visual cues necessary for their performance are essentially the same, the two tasks (formation flight and inflight fueling) will be considered together.

a. Detection. Since rendezvous is usually over a fixed ground reference or celestial reference on the one hand, or occurs immediately after takeoff, detection falls into two categories.

(1) The threshold problem exists when either through visual contact or radar assist an interception has to be made in an airspace.

The first cue to be discussed here is velocity. If there is relative motion between the target to be intercepted and the interceptor, the probability of detection is increased.

Very little is known about the threshold for acceleration, so that any statement about the change in relative motion serving to lower the threshold for detection would be mere speculation.

The relative brightness of a point source (in this case the target aircraft), is obviously important for detection purposes, i. e., the brightness of the navigation lights of an aircraft will increase with decreased distance.

(2) The tracking task exists when the target aircraft is in full view from the outset, such as join-up immediately after takeoff. If the tracking task exists as defined then there is no problem.

b. Discrimination. This refers to a quantitative judgment about something in the visual field. The discrimination must be made as to the relative bearing of the target aircraft and its elevation; or, to state the case differently, the clock position (the position on the horizontal plane) must be ascertained as well as the position on the vertical plane.

One of the most important cues is the perceived distance between the target and the horizon. This serves as a fixed reference in that the position of the horizon on the windscreen relative to the position of the target is sufficient for localization on the vertical plane.

For ascertaining position on the horizontal plane the nose of the interceptor serves as the fixed reference.

For judging the effective distance, the previously mentioned information must be integrated with the visual angle described by the target; i. e., having prior knowledge of the type of target, a discriminative judgment of distance can be made on the basis of the size of the target. The elevation

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and clock positions of the target must be known despite the law of the visual angle holding true, as the physical distance is not always important for satisfactory completion of the task, e. g., during the join-up phase a speed advantage may be converted to an altitude advantage very quickly and with little danger of collision in most cases.

c. Identification. The wingman (or tankee) must identify the target in his visual field as a certain type of aircraft, which, in many cases, is of the same type as his own. The most important cue is shape; i. e., having prior knowledge of the kind of target to be intercepted, the shape would be recognized.

The size of the familiar object would also be an important cue.

d. Judgment. This is the most complex of all in that once having detected the target in space, having discriminated its position and range and identified it as a formation leader or tanker aircraft, the distance between the two aircraft must be gradually reduced to the point where the relative motion between them averages zero.

### Functional Analysis

During the early stages of join-up with the target aircraft, it will appear to the wingman that the shape of the target is changing; size seems to grow slowly at first, then more rapidly during the later stages of closure. There will be increased resolution of detail with decreased distance, and shadow patterns may change as the target aircraft changes its position relative to the sun. The brightness of the aircraft changes with decreased distance due to atmospheric attenuation or aerial perspective; related to this is the fact that any texture present may be more readily identified as range decreases. Relative speed (while often indistinguishable at first) becomes increasingly obvious with decreased distance; this is also the case for acceleration. There is also a gradual shifting of the source of information for velocity and acceleration, i. e., initially the actual speed of the target aircraft is usually known, so that relative speed is judged by relating speed shown on the airspeed indicator of the interceptor with the known speed of the target aircraft. The same general statement holds for acceleration. However, as the range decreases the source of this information comes less and less from the integrating of cockpit instrument readings with known target speeds, and more and more from a visual judgment of the target in relation to the interceptor.

There is also a similar shifting of the source of information to maintain aerodynamic stability, i. e., information needed for control of roll, pitch and yaw. At first the cues come from the external visual world as well as the cockpit instruments of the interceptor, e. g., the external cues

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would be angle and elevation of the horizon on the windscreen for roll and pitch, and azimuth from the X-point for yaw.

As the interceptor pilot approaches the target, his scan pattern is forced out of the cockpit to an increasingly greater extent, i. e., he refers less to his cockpit instruments and more to the external horizon and target aircraft. Still later during the closure or join-up task there is a shifting of attention within the cues from the external visual world, i. e., the horizon becomes less important for pitch and roll information as the target aircraft now provides this information during close formation. In short, initially there is alternation between inside and outside cues; later, alternation only between outside cues; and finally, there is viewing only of the target aircraft.

Clearly, formation flying and aerial refueling require complex time-sharing. This is especially true for the join-up phase which necessitates a gradual shifting of visual attention, both between and within the available classes of intra- and extra-cockpit cues. This type of training could be given in a simulator such as the F-100/151.

### SECTION III

#### A STUDY OF THE PERCEPTUAL CHARACTERISTICS AND TRAINING POTENTIAL OF AN EXTERNAL VISUAL DISPLAY:

##### BRIEF OF THE EXPERIMENT\*

##### A. INTRODUCTION

Most flight simulators in use for training purposes by the Navy have no external visual display, and for this reason cannot be used for training in contact flight. Training for emergencies and aircraft control in simulators without an external display has of necessity been part-training.

In this experiment, certain activities in which fixed-wing pilots normally engage were selected to coincide with certain conditions of flight, the conditions of flight being fairly representative of most of the conditions normally encountered in the real world situation. Assuming that emergencies are just as likely to occur under instrument conditions as in contact flight, then training for the detection of these emergencies ought to occur under both conditions. With these factors in mind, the study was set up to investigate the improvement in pilot time-sharing in a real-world flight task using the F-100/151 fixed gunnery trainer. More specifically, the questions to be answered are as follows:

- (1) What is the training potential of a flight simulator with a non-programmed visual display?
- (2) What kinds of visual time-sharing behavior are observed, and what are the implications of this behavior with regard to training to improve performance?

##### B. METHOD

Time-sharing was investigated through the use of such measures as the time to detect emergencies (latency) as well as altitude-holding ability. The latency scores were used as an index of emergency detection behavior, and the altitude scores as an index of aircraft control.

##### C. APPARATUS

The apparatus consisted of an F-100/151 fixed gunnery trainer. This simulator system includes three major components:

- (1) The flight simulator (F-100) consisted of the cockpit and all the controls in the F-100A aircraft.

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\*Refer to Appendix A for a detailed account of the experimental study.



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(2) The external visual display (151) consisted of a large hemisphere surrounding the F-100A simulator onto which a horizon could be projected as well as target aircraft.

(3) An instructor's console, well out of view of the subject, provided for positive control of the training/experimental situations, and permitted direct readout of the subject's behavior.

### D. SUBJECTS

Ten experienced Naval and Marine aviators served as subjects, half of whom were jet qualified pilots and half were multi-engine reciprocating pilots. Their pilot hours ranged from 500 to 7000.

### E. PROCEDURE

The experimental task consisted of four training sessions for each subject; however, prior to the initiation of training, an orientation was given with regard to the purpose of the study, the various conditions of flight, and the mission. The conditions of flight were: (1) formation flight with an external horizon present; (2) formation flight with no external horizon; (3) single aircraft flight with an external horizon; and (4) single aircraft flight with no external horizon. The mission consisted of flying as well as possible under all of the conditions of flight while reporting all intruder aircraft (outside emergencies) and cockpit emergencies (inside emergencies) as quickly as possible.

### F. CONCLUSIONS

1. **EMERGENCY DETECTION BEHAVIOR.** In general it was found that the pilots improved their performance with training for the different conditions of flight as well as the different classes of emergencies. This was interpreted to mean that the F-100/151 has training potential for teaching visual time-sharing. Some of the interactions and simple effects also indicate that time-sharing training is needed, e. g., detection times for emergencies both inside and outside the cockpit were differentially affected as a function of flying singly or in formation; performance was better while flying singly than while flying in formation. This is interpreted to mean that there is a need for time-sharing training.

Another interesting finding was that the addition of the external visual horizon had no overall effect on emergency detection behavior; in addition there were no interactive effects as a function of the presence or absence of the external horizon. The obvious interpretation of these facts is that the horizon was difficult to see, in fact some of the subjects reported initial non-use of the horizon because of its lack of sufficient contrast between sky and ground.

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2. **AIRCRAFT CONTROL BEHAVIOR.** In general it was found that the pilots improved their performance with training under all the different conditions of flight. This was interpreted to mean that the F-100/151 has potential for teaching perceptual motor time-sharing. Some of the interactions again indicate the need for this training, e. g., the presence or absence of an external horizon is differentially important as a function of flying in formation or singly. This finding also supports the conclusion that there is a need for integrated procedures training.

Even more interesting was the fact that the presence or absence of the external horizon did make a difference for aircraft control behavior despite its being difficult to see; whereas it made no difference in terms of emergency detection behavior.

3. **GENERAL CONCLUSIONS.**

- a. The time-sharing study using the F-100/151 fixed gunnery trainer reflects the need for proper time-sharing training as well as the possibilities for just such training in the same simulator with the improved horizon previously discussed in the recommendations section.

- b. The pilots who performed best in terms of emergency detection did not necessarily perform best in terms of aircraft control; in fact the relationship was close to zero. This lack of relationship may be used in support of the contention that the highly skilled pilots used in this study need time-sharing training.

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APPENDIX A

A STUDY OF THE PERCEPTUAL CHARACTERISTICS  
AND TRAINING POTENTIAL OF AN  
EXTERNAL VISUAL DISPLAY

A. INTRODUCTION

Most flight simulators in use for training purposes by the Navy do not include an external visual display and, for this reason, cannot be used for training in contact flight. Training for emergencies and aircraft control in simulators without an external visual display has of necessity been part-training. This study does not propose to solve the whole vs. part issue; however, it does represent a bridging of the issue,\* in that certain activities in which fixed wing pilots normally engage were selected to coincide with certain conditions of flight--the conditions of flight being fairly representative of most of the conditions normally encountered in the real-world situation. Assuming that emergencies are just as likely to occur under instrument conditions as contact flight, then training for the detection of these emergencies ought to occur under both conditions. In addition, the factor of aircraft control should also be integrated with emergency detection. To state the case differently, the simulator should teach time-sharing between visual cues as well as between the visual cues and the perceptual motor skill itself.

Some of the work already done in the area of the cue components necessary for adequate simulation of contact flight includes that of Payne et al. (25), Gibson et al. (13) and Roscoe (26). Actually, very little is known about the stimulus elements that constitute the contact situation.

The issue of integrated training as opposed to part training is related to the part vs. whole controversy which has been with us for the past sixty years. The present study was set up with a holistic bias; however, it does not represent a test of integrated vs. part procedures training since it was primarily set up to investigate the improvement in pilot time-sharing in a real-world flight task using the F-100/151 fixed gunnery trainer.

B. METHOD AND RATIONALE

Time-sharing was investigated through the use of emergency detection time (latencies) and altitude holding ability. Time-sharing as originally conceived in this design, involved more than just simply the sharing of the

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\* The part-tasks used were quite global in scope and included a larger number of sub-tasks.

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visual scan pattern inside and outside the cockpit, but also involved the primary task of aircraft control with respect to the visual scan patterns inside and outside the cockpit. This permits the comparison of emergency detection behavior (latency data) with aircraft control behavior (altitude variability data).

These two dependent variables may be considered as independent observations in that the pilot subjects were not aware of the fact that while their altitude-holding variability was being measured, emergencies either might or might not occur. From the experimenter's point of view also, the observations were definitely independent since, whenever altitude measures were being taken, latency measures were not.

It was assumed that during visual time-sharing using our latency data, several things should occur with increased training. The over-all latencies should decrease, as well as any observed differences between outside and inside cockpit latencies. The same thing should hold true with regard to the altitude dependent variable measure. As latencies to inside and outside cockpit emergencies decrease, with increasing training, the variability in the altitude holding should also decrease; so that, ideally, the particular subject in question should improve not only in his visual scan pattern, but should also improve in his ability to hold altitude.

The design used for the latency dependent variable measure appears as Figure 11. The design for which altitude variability represented the dependent variable appears as Figure 12.

### C. APPARATUS

The apparatus consisted of an F-100/151 fixed gunnery trainer (Figure 13) which can be discussed in two parts:

(a) The simulator (F-100) consisted of the cockpit and all the controls in the F-100A aircraft.

(b) The external visual display (151) consisted of a large hemisphere surrounding the F-100A simulator onto which a horizon could be projected as well as target aircraft. A television system was used for projecting target aircraft onto the horizon and a lens system was used for projecting the horizon. Additional apparatus consisted of two slide projectors which were used to project target aircraft on the hemisphere. This permitted the simultaneous presentation of two intruder aircraft:\*

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\*See Glossary, page 118.



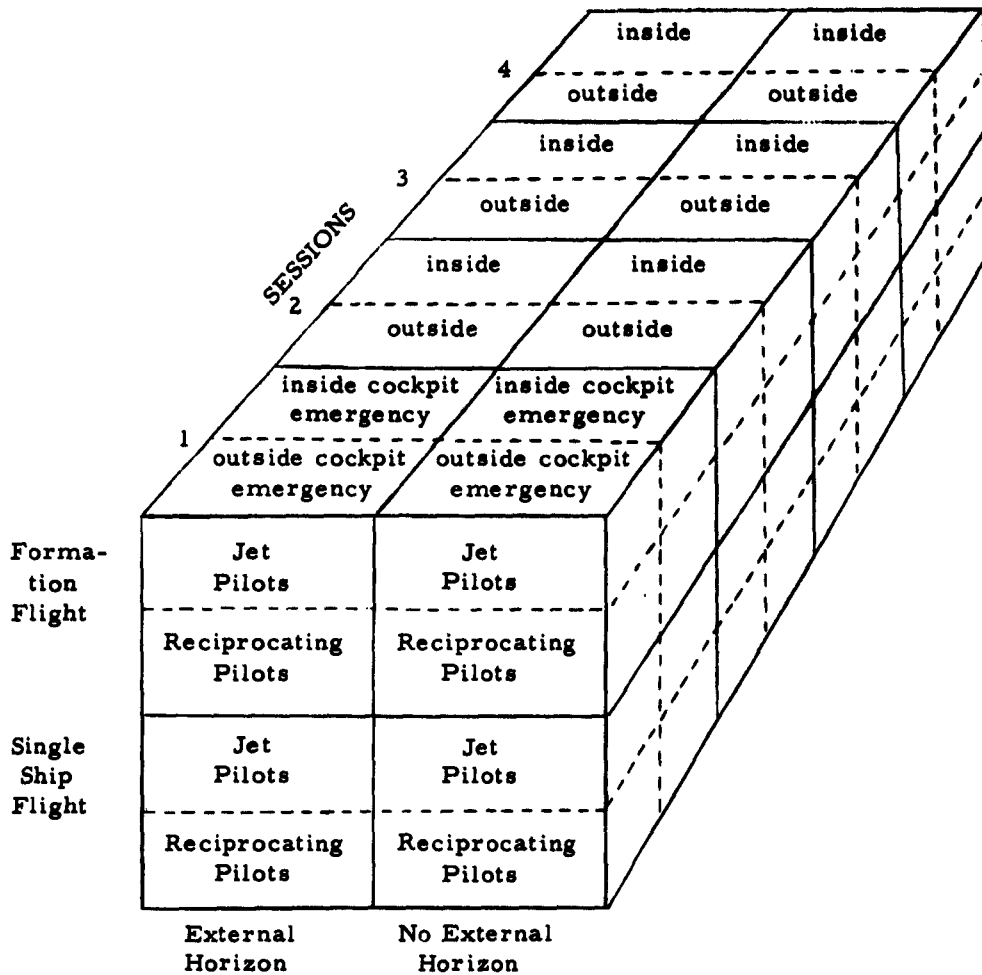


Figure 11. Flight Simulator Experimental Design (emergency data only)

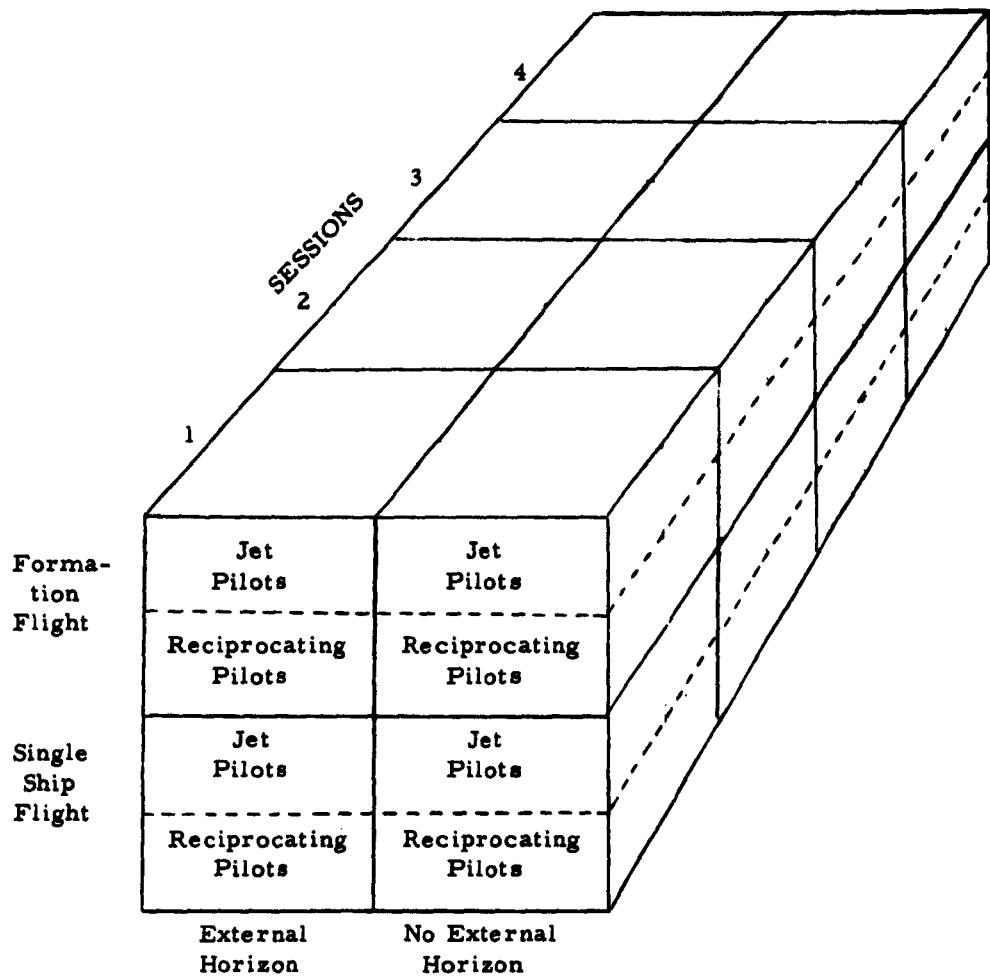


Figure 12. Flight Simulator Experimental Design (altitude data only)

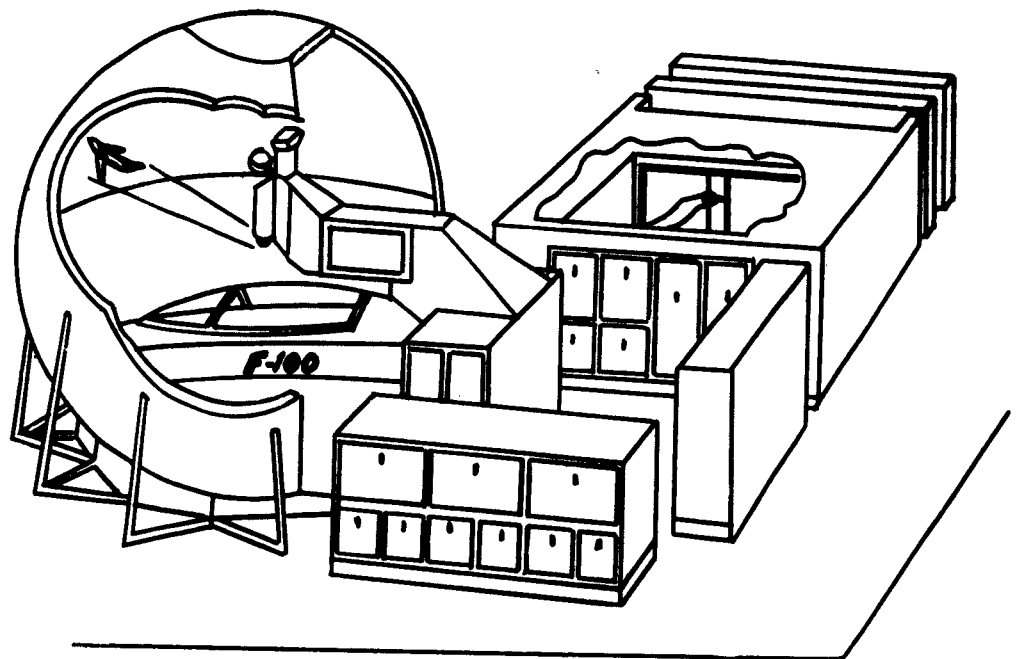


Figure 13. F-100/151 Fixed Gunnery Trainer

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- (1) TV targets (bogies) with the television system;
- (2) Projector targets (bogies) with the slide projector system.

Horizon and target aircraft could be turned on or off by the instructor.

In addition there was an instructor's console well out of the view of the subjects (pilots), which permitted direct readout of the subjects' performance, i.e., most of the cockpit instruments were duplicated at the instructor's console.

### D. SUBJECTS

Ten experienced Naval and Marine aviators served as subjects, half of whom were primarily jet pilots and half of whom were primarily multi-engine reciprocating pilots. Their pilot hours ranged from 500 to 7000. Since almost all jet pilots had considerable flight time in reciprocating engine aircraft, the distinction was of necessity somewhat arbitrary. The criterion used to distinguish jet pilots from reciprocating pilots was 101 or more hours of jet time. There are very few Naval jet pilots who have no reciprocating engine time. The most usual case is one in which the jet pilots in the population have considerable prior or concurrent reciprocating engine flight time. Experience levels are presented in Tables 1 and 2.

### E. PROCEDURE

1. **SUBJECT ORIENTATION.** Prior to the beginning of Session 1, each pilot (subject) was given an orientation regarding the purpose of the study, the various conditions of flight and the mission. The mission consisted of flying under all the experimental conditions, while reporting all intruder aircraft (bogies) and within-cockpit emergencies (that might occur) as soon as possible. It was also stressed that when flying under the horizon conditions (VFR), the external visual horizon should be used as if in contact flight. This was necessary as the subjects were not accustomed to flying simulators with an external visual display. Orientation of each subject included the following specific points:

- (1) Greet pilot.
- (2) Orient pilot regarding the purpose of study, i.e., (a) improve perceptual characteristics of the simulator; (b) investigate the training potential of the simulator with respect to time-sharing.
- (3) Tell pilot that he will be given only general information concerning how well he did after each session.

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Table 1

Rank Order of Pilot Subjects Based on Total Flight Hours  
As Estimated by the Subjects Themselves

Jet and Reciprocating Pilots		Reciprocating Only	
1	3600	1	7000
2	3200	2	6400
3	2000	3	4200
4	1800	4	3500
5	1100	5	500

Table 2

Experience Level of Pilot Subjects Based on Their Own Estimates

	Jet Qualified					Reciprocating Only				
	1	2	3	4	5	1	2	3	4	5
Jet and Recipro- cating Pilot (*)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No
Total Hours	3600	3200	2000	1800	1100	7000	6400	4200	3500	500
Instrument Time (X)	150	400	350	250	350	750	700	500	400	100
Number of Simu- lators Flown	5	1	-	2	2	1	2	-	4	-

\* Criterion used to distinguish jet pilots from reciprocating pilots was 101 or more hours of jet time

X Simulated plus actual

- Data not available

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- (4) Ask pilot not to discuss experiment with others.
  - (5) Seat pilot in the cockpit and go over "check-off" list.
  - (6) Emphasize trim button, throttle, speed brakes, mike button, and heading indicator.
  - (7) Demonstrate proper corrective procedures for all emergencies.
  - (8) Give pilot power settings and airspeed for climb and air work.
  - (9) Require 30° bank for all turns except when intercepting targets, in which case the pilot must use his own judgment.
  - (10) Warn pilot that other aircraft (one or more) may be presented on the external display from time to time. He is to report them as soon as possible. Demonstrate "bogies."
  - (11) Inform pilot that cockpit emergencies will be presented from time to time. He should report them and then take corrective action as rapidly as possible.
  - (12) Explain elevator and aileron button.
  - (13) Explain limitation of the vertical speed indicator. (Maximum indication of vertical speed is 6000 feet per minute.)
  - (14) Explain formation flying and how to hold target: (a) lateral separation 2000 feet; (b) maintenance of clock position of the target aircraft; (c) stack level; (d) initial speed advantage over target; (e) reduction of speed in turn; (f) range information limited to the horizontal plane; (g) type of target (F-100).
  - (15) Emphasize the realism of the simulator in terms of hallucinated movement sensations ("seat-of-the-pants cues").
  - (16) Emphasize two-position speed brake button: in or out only.
  - (17) Take "check-off" list from pilot.
2. THE EXPERIMENT. The experiment consisted of four experimental sessions for each of ten pilots. There were four sub-sessions in each session, and each sub-session conformed with one of the conditions of the experiment. Selection of the four conditions was on the basis of (a) maximizing the probability of the subject's visual scan pattern being either outside or inside the cockpit, as well as for purposes of (b) varying the complexity of the task. The conditions are presented in Table 3; for more detail

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regarding conditions, independent variables and dependent variables, see Table 5.

Table 3

## Matrix Representing External Visual Conditions Encountered by All Pilots

	External Horizon Present	No External Horizon
Formation Flight	A	B
Single Aircraft Flight	C	D

The conditions were counterbalanced to minimize any transfer effects from one condition to the next; however all pilots followed the same sequence.\* Table 4 illustrates this counterbalancing. The numbers in the cells of the matrix represent the sequence of presentation of sub-sessions.

Table 4

## Counterbalancing of Conditions

Conditions	Sessions			
	1	2	3	4
A	3	1	4	2
B	4	3	2	1
C	1	2	3	4
D	2	4	1	3

Most of the subjects completed their four sessions within a two-day period, with two sessions per day and a rest period intervening. There was a deviation from this only for two subjects and then only because of equipment breakdown or unavailability of the subject.

\* The most difficult condition occurred first during session one and last during session four.

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Table 5

The Independent Variables (or Tasks) Used  
And Their Dependent Variable Measures\*

Duration (min.)	Condition	Independent Variable	Dependent Variable
13	Single aircraft flight with external horizon	1) cockpit emergencies 2) spotting targets 3) level turns	latency latency altitude
13	Single aircraft flight; no external horizon	1) cockpit emergencies 2) spotting targets 3) level turns	latency latency altitude
17	Formation flight with external horizon	1) cockpit emergencies 2) spotting targets 3) flying loose formation	latency latency altitude
17	Formation flight; no external horizon	1) cockpit emergencies 2) spotting targets 3) flying loose formation	latency latency altitude
* The approximate time required for completion of each condition is also included.			

A non-correction method was used in that the subjects were given no specific information regarding their performance till they completed all four sessions.

The flight program to be given to the subjects was test flown and during which a complete script was devised for the entire flight task from takeoff to landing. This script appears below.

## 3. THE SCRIPT.\*

### Take Off and Climb

1. "NAVY ONE FIVE ONE CLEARED TO AND HOLD SHORT OF  
RUNWAY THREE ONE; WIND NORTHWEST AT FIVE KNOTS;  
ALTIMETER TWO NINE NINE TWO."

\* At times necessary deviations were made from the formality of this script for purposes of realism. (See Appendix A)



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2. "NAVY ONE FIVE ONE CLEARED FOR TAKE OFF; CLIMB TO TWO ZERO THOUSAND; MAINTAIN HEADING THREE ONE ZERO DEGREES; REPORT REACHING TWO ZERO THOUSAND."
3. "MAINTAIN TWO ZERO THOUSAND AND HOLD THREE FIVE ZERO KNOTS INDICATED AIRSPEED AND HEADING THREE ONE ZERO DEGREES TILL FURTHER ADVISED."

Formation Flying With External Horizon

1. "TURN RIGHT TO THREE SIX ZERO DEGREES AND MAINTAIN THAT HEADING."

(Not measured) a. Target (formation leader) presented at 10 o'clock, 30 seconds after roll-out; range 5,000 feet.

2. "INTERCEPT TARGET AS IF JOINING UP IN FORMATION (STARBOARD SIDE); MAINTAIN TWO THOUSAND FEET LATERAL SEPARATION AND THE SAME ALTITUDE AS THE TARGET. YOU WILL HAVE A FIFTY KNOT SPEED ADVANTAGE; TARGET HEADING THREE SIX ZERO DEGREES."

(Latency) a. Inverter failure 10 - 30 seconds after join-up.

3. "TARGET WILL NOW ACCELERATE TO THREE FIVE ZERO KNOTS INDICATED AIRSPEED."

a. Target set at 460 knots true airspeed. (460 true = 350 indicated)

(Latency) b. Bogie (intruder) presented at 2 o'clock high, 30 seconds after speed has stabilized.

(Not measured) c. Hydraulic failure 10 - 30 seconds after bogie appears.

4. "TARGET WILL NOW TURN RIGHT TO ONE EIGHT ZERO DEGREES; YOU WILL REMAIN ON INSIDE OF TURN WITH TWO THOUSAND FEET LATERAL SEPARATION AND MAINTAIN ALTITUDE."

a. Switch target to 2 o'clock position after roll-out.

(Latency) b. Tail pipe overheat 10 - 30 seconds after roll-out.

5. "TARGET WILL NOW TURN LEFT TO ZERO NINE ZERO DEGREES; YOU ARE TO REMAIN ON INSIDE OF TURN WITH TWO THOUSAND FEET LATERAL SEPARATION AND MAIN-

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TAIN ALTITUDE."

- (Latency) a. Bogle (intruder) presented at 2 o'clock high, 10 - 30 seconds after roll-out.

Formation Flying Without External Horizon

1. "TURN LEFT (OR RIGHT) TO THREE SIX ZERO DEGREES AND HOLD THAT HEADING."

- (Not measured) a. Target (formation leader) presented at 10 o'clock, 10 - 30 seconds after roll-out at 5,000 feet range.

2. "INTERCEPT TARGET AS IF JOINING UP IN FORMATION (STARBOARD SIDE); MAINTAIN TWO THOUSAND FEET LATERAL SEPARATION AND THE SAME ALTITUDE AS TARGET. YOU WILL HAVE A FIFTY KNOT SPEED ADVANTAGE; TARGET HEADING THREE SIX ZERO DEGREES."

- (Latency) a. Bogle (intruder) presented at 10 o'clock high, 10 - 30 seconds after join-up.

3. "TARGET WILL NOW ACCELERATE TO THREE FIVE ZERO KNOTS INDICATED AIRSPEED."

- a. Target set at 460 knots true airspeed.

- (Latency) b. Tail pipe overheat 10 - 30 seconds after speed has stabilized.

- (Altitude Measure) 4. "TARGET WILL NOW TURN RIGHT TO ONE EIGHT ZERO DEGREES; YOU REMAIN ON INSIDE OF TURN WITH TWO THOUSAND FEET LATERAL SEPARATION AND MAINTAIN ALTITUDE."

- a. After turn, switch target to 2 o'clock position, same range.

- (Latency) b. Inverter failure 10 - 30 seconds after roll-out.

- (Latency) c. Bogle (intruder) presented at 10 o'clock high, 10 - 30 seconds after inverter failure.

5. "TARGET WILL NOW TURN LEFT TO ZERO NINE ZERO DEGREES; YOU REMAIN ON INSIDE OF TURN WITH TWO THOUSAND FEET LATERAL SEPARATION AND MAINTAIN ALTITUDE."

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(Not measured) a. Oil cooler overheat 10 - 30 seconds after initiation of turn.

Single Aircraft Flying with External Horizon Present

1. "TURN RIGHT (OR LEFT) TO THREE SIX ZERO DEGREES AND HOLD THAT HEADING."

(Latency) a. Inverter failure 10 - 30 seconds after roll-out.

2. "TURN LEFT TO TWO SEVEN ZERO DEGREES AND HOLD THAT HEADING."

(Not measured) a. Generator failure 10 - 30 seconds after initiation of turn.

(Not measured) b. Bogle (intruder) at 1 o'clock high, 10 - 30 seconds after roll-out.

(Altitude Measure) 3. "TURN RIGHT TO ZERO NINE ZERO DEGREES AND HOLD THAT HEADING; REDUCE INDICATED AIRSPEED IN YOUR TURN FROM THREE FIVE ZERO KNOTS TO THREE ZERO ZERO KNOTS; USE YOUR SPEED BRAKES."

4. "INCREASE SPEED TO THREE FIVE ZERO KNOTS INDICATED; HOLD HEADING ZERO NINE ZERO DEGREES."

(Latency) a. Tail pipe overheat 10 - 30 seconds after speed has stabilized.

(Latency) b. Bogle (intruder) at 10 o'clock high, 10 - 30 seconds after tail pipe overheat.

5. "TURN LEFT TO THREE SIX ZERO DEGREES AND HOLD THAT HEADING."

(Latency) a. Bogle (intruder) at 10 o'clock high, 10 - 30 seconds after roll-out.

Single Aircraft Flying Without External Horizon Present

1. "TURN LEFT (OR RIGHT) TO THREE SIX ZERO DEGREES AND HOLD THAT HEADING."

(Latency) a. Tailpipe overheat 10 - 30 seconds after roll-out.

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2. "TURN LEFT TO TWO SEVEN ZERO DEGREES AND HOLD THAT HEADING."

(Not measured) a. Windshield overheat 10 - 30 seconds after initiation of turn.

(Not measured) b. Projector bogie at 11 o'clock high 10 - 30 seconds after roll-out.

3. "TURN LEFT TO ZERO NINE ZERO DEGREES AND HOLD THAT HEADING. REDUCE AIRSPEED IN TURN FROM THREE FIVE ZERO KNOTS TO THREE ZERO ZERO KNOTS. USE YOUR SPEED BRAKES."

(Altitude Measure)

4. "INCREASE SPEED TO THREE FIVE ZERO KNOTS. HOLD HEADING ZERO NINE ZERO DEGREES."

(Latency) a. Inverter failure 10 - 30 seconds after speed has stabilized.

(Latency) b. Projector bogie at 2 o'clock high 10 - 30 seconds after inverter failure.

5. "TURN LEFT TO THREE SIX ZERO DEGREES AND HOLD THAT HEADING."

(Latency) a. Projector bogie at 2 o'clock high 10 - 30 seconds after roll-out.

4. RULES FOR PRESENTING AND RECORDING EMERGENCIES AND TARGET AIRCRAFT (BOGIES)

1. Targets (Outside-Cockpit Emergencies Consisting of Intruder Aircraft)

a) All targets were presented to subject while he was in straight and level flight.

Design Considerations

This was done to maintain maximum control over events that might influence the pilot's visual perception of the target. Because the projector target was in a fixed position relative to pilot and the hemisphere, and the horizon moved relative to pilot and simulator; and because brightness above horizon was greater than below horizon, differing contrast ratios could have resulted had the aircraft been in a turn when the

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projector target was presented. The pilot may also have been predisposed toward looking in the direction of the turn rather than opposite the direction of the turn. It was necessary to insure that when the target was presented, the pilot was not predisposed toward looking in one direction.

- b) All projector targets occurred in four positions relative to the subject: 2 and 10 o'clock high, 1 and 11 o'clock high.

**Design Considerations** The 2 and 10 o'clock positions were selected so that an individual with normal vision, looking out at 12 o'clock level and knowing that the target was to appear, would be able to detect it.

The high position was chosen so that the target would always occur in the brighter part of the hemisphere. The target contrast ratios were approximately the same for horizon and no horizon conditions and well above threshold when fixated with central vision.

**Practical Considerations** Equipment limitation did not permit greater variation than 9-11 o'clock, high through level elevation, and 1-3 o'clock, high through level elevation.

- c) The range and bearing of all TV targets were static until recognition by the pilot. The initial range was 5000 feet with a broad-side view.

**Design Considerations** Since the TV target served as the equivalent of a non-recorded projector target in the formation conditions, it was necessary to maintain its size the same as that of the projector target. This resulted in minimization of any differences in non-recorded targets over conditions.

The range of 5000 feet for TV targets was the equivalent in size of the Projector targets. The TV target was an F-100.

**Practical Considerations** Any range (within limits) of the TV target could have been presented, but freedom was lost in fixing the range of the projector targets. This range was selected to put target aircraft well above threshold as previously explained.

- d) Projector targets occurred at 2 and 10 o'clock high during each sub-session (condition).

**Design Considerations** Although three targets were presented during each sub-session, only two were recorded. The third was presented in random spatial positions to prevent positional hypotheses

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on the part of the subjects (pilots).

The high elevations were selected to force the pilot's scan pattern far enough out of the cockpit so as not to permit simultaneous scanning of outside visual world and cockpit visual world.

The reason for two recorded presentations during each sub-session was to have at least one replication for each subject under each condition for this emergency. This was done to increase the stability of performance measures. Replications were desirable without sacrificing too much realism and it is not at all unlikely that three aircraft would be sighted during a 15-minute period in the real world situation.

- e) Only the latencies to positions 2 and 10 o'clock high were recorded as performance measures.

Design Considerations	The responses to these when pooled would counteract a left or right position tendency on the part of the subject.
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Practical Considerations	The number of performance measures had to be limited as the experimenters were busy setting up tasks, conditions, making radio calls and answering them.
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- f) All targets for which the performance measure was latency were presented with a slide projector system.

Design Considerations	Although not all targets were presented with the slide projector system, all recorded ones were. The obvious reason is that any other method would have resulted in confounding across the condition variable, across the emergency variable, as well as between these two variables.
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Practical Considerations	Since the formation tasks required the presence of two targets (one on which to fly formation, and another to serve as an intruder) it was necessary to utilize both the TV projector and the slide projector systems.
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- g) Latencies were measured between presentation of stimulus and initiation of verbal report.

This was for both the inside and outside cockpit emergencies and made the two measures comparable.

Here we were forced to deviate somewhat from realism, since in the real world situation the pilot is likely to respond

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**Design Considerations** to the emergency first and then report it later. Actually, our subjects did both, but were asked to report verbally first. No difficulties of any significance were encountered because of this approach.

**Practical Considerations** Here again we had a practical limitation, since the corrective action for inside cockpit emergencies could be directly observed at the instructor's console, whereas the corrective action taken to outside cockpit emergencies could not.

### 2. Emergencies (Inside Cockpit Emergencies)

#### a) Emergencies occurred in straight and level flight and turns.

**Design Considerations** The reason for presenting emergencies in both of these situations was to give the pilot a set that emergencies could occur at any time. While it is true that the targets (bogies) were not presented in turns, thus making inside and outside emergencies non-equivalent on this basis, the subjects did not know this and continued their visual search behavior both inside and outside the cockpit during straight and level flight and turns. The outside visual search behavior of several of the subjects disappeared by the 4th session (based on interview data.)

**Practical Considerations** Some turns had to be reserved for collecting altitude data.

#### b) A total of three emergencies occurred during every sub-session. For two of these, latency measures were recorded; these recurred during every sub-session. The remaining unrecorded emergency was different for each sub-session. Thus, there was a total of six different emergencies.

**Design Considerations** Since the area of visual search in the cockpit was less than that in the outside visual world, it was considered desirable to have additional different emergencies located at various points around the cockpit to force searching behavior in all directions where inside emergencies could have occurred.

The six emergencies were selected on the basis of forcing a complete scan pattern, and ease of corrective action. The ease of corrective action needs clarification in that our intention was to study an aspect of visual perception, not motor response. Thus, there was no need to use emergencies that required a complex motor response. On the other hand, realism could not be discarded and this necessitated

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the selection of emergencies for which the corrective action would be simple and yet realistic.

In addition, the subjects had to be permitted to take corrective action so as to give them a sense of closure.

- c) Emergencies were presented for a duration of one minute, after which they were removed, i.e., corrective action was taken by the experimenter.

### Design Considerations

Theoretically, an emergency could have gone undiscovered for the duration of the session (approximately one hour), in which case its presence would have overlapped the presence of other emergencies as well as other conditions. In order to prevent intra- and inter-variable confounding, it was necessary for each event (observation) to be independent of every other observation.

It was also decided to use a non-correction method of training in order to hold all stimulus materials constant for the subjects. Had the choice been made to use the corrective method, the number of corrections would have varied for different subjects; therefore, it was decided that a non-correction method would be used in the interest of consistency and that the stimuli (emergencies) would be removed by the experimenter after a period of 60 seconds total elapsed time.

- d) The emergencies for which latency measures represented dependent variables were: tail pipe overheat and inverter failure. These occurred in straight and level flight only.

### Design Considerations

These were selected on the grounds of their frequency of occurrence in a real world situation, their representativeness of the kinds of emergencies that occur, and their degree of criticalness, i.e., the necessity for corrective action to be taken in order for a flight to continue safely.

That they occurred in straight and level flight was necessary in order to make the latency measures comparable



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with outside cockpit emergencies, which also occurred in straight and level flight. The reason for selecting straight and level has been previously discussed.

- e) The remaining emergencies were generator failure, flight system hydraulic failure, oil cooler overheat and windshield overheat. These occurred in turns and straight and level flight.

Design Considerations	These emergencies were selected on the basis of their being representative of different degrees of criticalness, simplicity of corrective action, etc., the remaining reasons having been previously discussed.
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Practical Considerations	There were great practical limitations in that those selected had to be directly observable from the instructor's console in addition to all the previously mentioned considerations.
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- f) The recorded response to all emergencies was the latency between presentation and verbal report. The subjects were instructed to take corrective action after verbal report.

Design Considerations	While corrective action to inside emergencies could be directly observed on the instructor's panel, this was not true of outside emergencies. In order to keep the two types of emergencies equivalent in terms of response, verbal reports of emergencies were used for both types.
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### 5. RULES FOR RECORDING ALTITUDE WITH DESIGN CONSIDERATIONS AND PRACTICAL CONSIDERATIONS.

- 1. Altitude was recorded at 15-second intervals while the pilot was engaged in turning  $90^{\circ}$ , and decreasing the speed in the turn from 350 KTS IAS to 300 KTS IAS.

Design Considerations	Since pitch control is relatively difficult in the F-100/151, and changing speed in a turn adds to the complexity of the task, an improvement with training sessions would be expected. To state the case differently, the task had to be made complex enough so that an improvement would be reflected in the dependent variable.
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Practical Considerations	The task is one which occurs in the real world, thus reducing the possibility of confusion on the part of the pilot subject.
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2. Altitude was recorded while in a 30° bank at an assigned altitude of 20,000 feet.

### Design Considerations

The altitude and bank were selected with the stability factor in mind, i.e., at 20,000 feet aerodynamic stability is relatively difficult to maintain. Thus, a balance was maintained between artificially induced complexity and realism in that banking 30° at an altitude of 20,000 feet is fairly difficult if altitude is to be maintained, and yet this task should be within the repertory of operational pilots.

The climb up to 20,000 feet also represented a warm-up period for each subject during which no data were collected.

3. Emergencies were never presented while altitude was being recorded.

### Design Considerations

The subjects did not know when emergencies were going to be presented, so that in most cases their expectancies remained; however, from the experimenter's point of view, these observations were independent. This avoided response variable confounding.

## 6. CRITERION OF TRAINING SUCCESS.

In the present study an internal criterion of training success was used. The reasons for this are presented below:

- (1) The tasks performed were fairly representative of those in the real world situation.
- (2) The use of an external criterion was impractical as the conditions could not accurately be duplicated in a real world situation.
- (3) The subjects were highly sophisticated and this presumably reduced the probability of a significant improvement.

## F. RESULTS AND DISCUSSION

Three separate analyses were completed:

Analysis #1 -- A non-parametric analysis of variance using data on detection time for emergencies; (see Glossary, Page 118)

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Analysis #2 -- A non-parametric analysis of variance using data on altitude variability;

Analysis #3 -- Application of correlational techniques.

These analyses were directed toward determining the answers to several fundamental questions as follows:

- (1) What is the training potential of a flight simulator with a non-programmed visual display?
- (2) What kinds of visual time-sharing behavior are observed, and what are the implications of this behavior with regard to training to improve performance?

Presented in terms of the major dimensions of the experimental design, the results of the analyses follow:

### 1. ANALYSIS #1 (LATENCY DEPENDENT VARIABLE).

a. Conditions of Flight. For analysis purposes, this dimension was broken down as follows:

A = Formation vs. single aircraft flight

B = External horizon vs. no external horizon

Selection of these four conditions was on the basis of maximizing the probability of the subjects' scan pattern being either outside or inside the cockpit, as well as varying the over-all complexity of the task. A significant difference in latency values was expected and obtained for formation vs. single flight ( $p < .01$ ). It is believed that this was largely due to single aircraft flight being of less complexity, thus allowing more leisure time for emergency detection. This effect may have masked out the effect of horizon vs. no horizon.

More specifically, the greatest frequency of short latencies in response to inside and outside cockpit emergencies occurred under the single aircraft conditions. From this it is concluded that single aircraft flight as performed in this study, is a less complex task than formation flight, thereby affording the pilot more time to engage in emergency detection.

Although one might have expected a significant difference between the horizon-no horizon conditions on the grounds of more visual cues (external) being available under the horizon condition, this effect was not found. This will be discussed at greater length under the interactions involving this

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main effect.

b. Emergencies. For analysis purposes, the emergencies were broken into two classes as follows:

C = Inside cockpit emergencies vs. outside cockpit emergencies

The emergencies were chosen mainly with the time-sharing questions in mind. Training for emergencies in simulators without an external visual display has, of necessity, been part-training. It is believed by the authors that training for emergencies (inside and outside the cockpit) should be integrated with the kinds of flying that pilots encounter under real conditions.

An attempt was made to equate inside and outside emergencies on the basis of difficulty of detection, and it was found that there was no significant difference between them ( $p > .90$ )\*. However, the emergency dimension will play an important role in the interpretation of the interactions.

c. Type of Pilots. For analysis purposes, pilots were divided into two classes as follows:

D = Jet and reciprocating ( $n = 5$ ) vs. reciprocating only ( $n = 5$ )

A significant over-all pilot effect was expected and obtained ( $p < .01$ ). These results are attributed to the fact that the F-100/151 simulator approximated jet aircraft handling characteristics which presumably favored, at least initially, those with jet experience. Naturally, any pilot effect must be interpreted in light of the non-equivalence of these two classes of subjects. An interesting aspect of the analysis will be the comparison of their time-sharing behavior.

d. Sessions. There were four sessions, all of which were identical, with the exception of the order of conditions within sessions.

E = Training sessions 1 through 4

An over-all significant session effect was expected and obtained ( $p < .01$ ). This was thought to be due in part to the fact that all of the pilots, with the exception of one (who had 1/2 hour previous experience), were naive with regard to the F-100/151 simulator. In addition, the integrated method of training used in this study is not typically in use. Therefore, regardless of experience, an improvement might be expected as a function of sessions (increased training).

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\* I.e., the emergencies were essentially equivalent.

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e. Interactions. (A X B) = Formation vs. single aircraft X Horizon vs. no external horizon.

The four conditions and the reasons for using them\* are presented below: (low scores mean good performance)

- (1) Formation flight with external horizon was designed to:
  - a) increase probability of a scan pattern outside the cockpit (VFR);
  - b) increase complexity of the task;
  - c) induce longer latencies than in single aircraft flight.
- (2) Formation flight with no external horizon was designed:
  - a) as a task which required a primarily outside-cockpit scan pattern for which the outside visual cues were inadequate; thus requiring the pilot to alternate between the outside world (outside cockpit) and the inside world (inside cockpit); the usual case is one in which the formation leader's aircraft provides the wingman with cues for pitch, roll, yaw, velocity and acceleration; however, although these cues are readily available during actual close information, equipment limitations in this study necessitated a lateral separation of 2,000 feet and produced an ambient light level approximating night conditions. Thus, the above cues were available to a much lesser extent.
  - b) to be the most complex of all conditions; thus it was expected to result in longest latencies for outside cockpit emergencies.
- (3) Single aircraft flight with external horizon was designed:
  - a) as a task that would increase the probability of an external scan pattern (VFR) where aerodynamic stability could be maintained with either an external or an internal visual scan pattern; however, the external horizon provided no yaw information.
  - b) to result in lowest scores for the pooled emergency data; mainly due to the reduced complexity of the task.

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\* The over-all guiding principle was realism.

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- (4) Single aircraft flight with no external horizon was designed:
- a) as a task of reduced complexity where the probability of a visual scan pattern inside the cockpit is increased;
  - b) to result in next to the lowest pooled emergency scores;
  - c) as a condition where the inside cockpit emergency scores would be lowest of all for this condition;
  - d) as a situation wherein aerodynamic stability could not be maintained by use of external cues.

One might have expected a significant interaction on the grounds that the formation-single aircraft flying tasks would be differentially affected by the horizon-no horizon conditions; however, this was not found since the trend was the same for both conditions. The big factor seemed to be the complexity of the task and not the conditions under which it was performed (formation vs. single  $p < .01$ ). This has interesting implications with regard to the visual cues necessary for flight in that adding a visual cue (external horizon) seems to have had no differential effect, whereas one would think, on logical grounds, that it would. A plot (Figure 14) of the interaction should clarify this issue. The plot is also evidence of good time-sharing since performance did not differ significantly as a function of the presence or absence of a horizon. This may be mitigated by the fact that some subjects reported non-use of the external horizon. An example will be presented to clarify this issue. During single ship flight with an external horizon it is possible to maintain aerodynamic stability using either external visual cues (VFR) or inside cockpit visual cues (IFR), whereas this is not the case in the absence of an external visual horizon (IFR only). Apparently, the additional visual cues under the VFR conditions had no effect on visual time-sharing behavior when sessions, emergencies and pilots were pooled.

-----  
(A X C) = Conditions (formation vs. single aircraft flight) X  
Emergencies (inside vs. outside)

A significant interaction was expected and obtained ( $p < .05$ ), largely, it is believed, because there were both inside and outside conditions as well as inside and outside emergencies; i.e., the inside emergencies presumably favored the conditions which required an inside cockpit orientation and the outside emergencies favored the conditions which required an outside cockpit orientation. An additional variable which influences those discussed above is the complexity of the task. This has presumably demonstrated itself in the interaction and thus influences the interpretation of the interaction. Since formation flying involves all the problems in the

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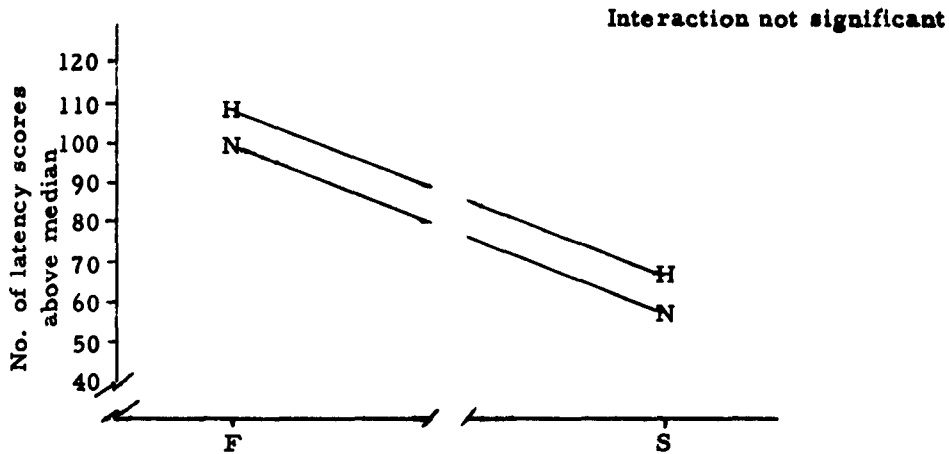


Figure 14. A x B interaction where H represents Horizon, N = No horizon, F = Formation flight, and S = Single aircraft flight.

Table 6

Nonparametric analysis of variance: formation vs. single aircraft flight, and horizon vs. no horizon (effect on latency scores)

Source of Variation	Chi sq.	df	Significance
A. Formation vs. Single Aircraft Flight	48.41	1	$p < .01$
B. External Horizon vs. No External Horizon	2.02	1	NS
A x B Interaction	.01	1	NS

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single ship flight plus maintaining position in relation to the formation leader, it is believed that the interaction was partly due to the differential effect of complexity of certain conditions on emergencies. At least part of this interaction must be attributed to the fact that the conditions were designed to realistically produce differential effects (formation vs. single aircraft significant,  $p < .01$ ), i.e., they were realistically not equivalent to begin with. The effects of even greater interest will be conditions and emergencies over sessions.

Figure 15 will clarify the interaction.

-----  
(A X D)=Conditions (formation vs. single aircraft flight) X Pilot Type  
(jet vs. reciprocating)

A significant interaction was neither expected nor obtained despite the fact that on seemingly logical grounds, the formation task would appear to favor jet pilots much more than would the single aircraft flight task. Again the trend remained the same. Figure 16 illustrates this trend. Of some interest is the fact that the time to detect emergencies differed significantly for jet and reciprocating pilots ( $p < .01$ ). It must be pointed out again that the conditions were not equivalent at the outset and it was not the intent of the experimenters to make them equivalent. The most important principle governing conditions was realism. The significant difference between formation vs. single aircraft flight strongly suggests the need for integrated procedures training. This difference indicates that there is a greater frequency of long latencies associated with emergency detection while flying in formation than when flying singly.

-----  
(B X C)=Conditions (horizon vs. no horizon) X Emergencies (inside vs. outside)

Here the effect of formation vs. single aircraft flight seems to have masked out the effect of horizon vs. no horizon. It was originally planned that the horizon vs. no horizon conditions would predispose the subjects to view the external visual world or cockpit instruments with differential frequency and time as a function of the two horizon conditions. Just such a trend (Figure 17) for the inside cockpit emergencies is evident; however, the interaction did not achieve significance. It must be pointed out that there was some intra-variable confounding for the outside cockpit emergencies; however, the fact that the Chi square for latency scores on emergencies was markedly insignificant mitigates this issue considerably.

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(B X D)= Conditions (Horizon vs. no horizon) X Pilot Type (jet vs. reciprocating)

The trend obtained in Figure 18 was not at all expected and thus warrants



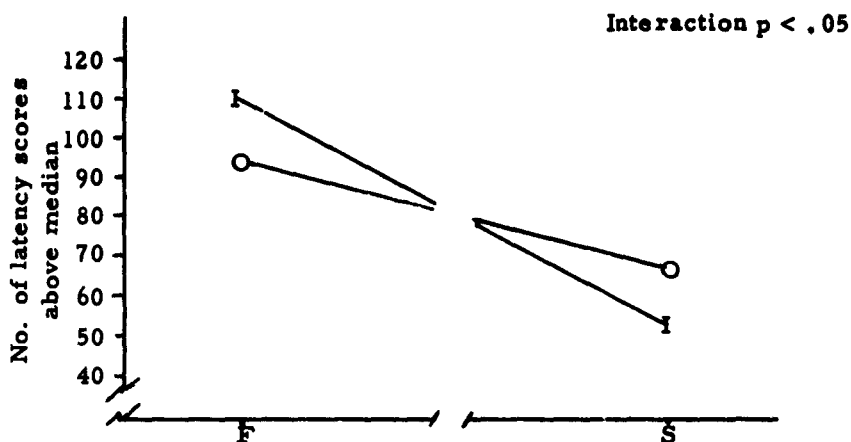


Figure 15. A x C interaction where I represents Inside cockpit emergencies, O = Outside cockpit emergencies, F = Formation flight, S = Single aircraft flight.

Table 7

Nonparametric analysis of variance: formation vs. single aircraft flight, and inside vs. outside emergencies (effect on latency scores)

Source of Variation	Chi sq.	df	Significance
A. Formation vs. Single Aircraft Flight	48.41	1	$p < .01$
C. Inside vs. Outside Emergencies	.02	1	NS
A x C Interaction	4.91	1	$p < .05$

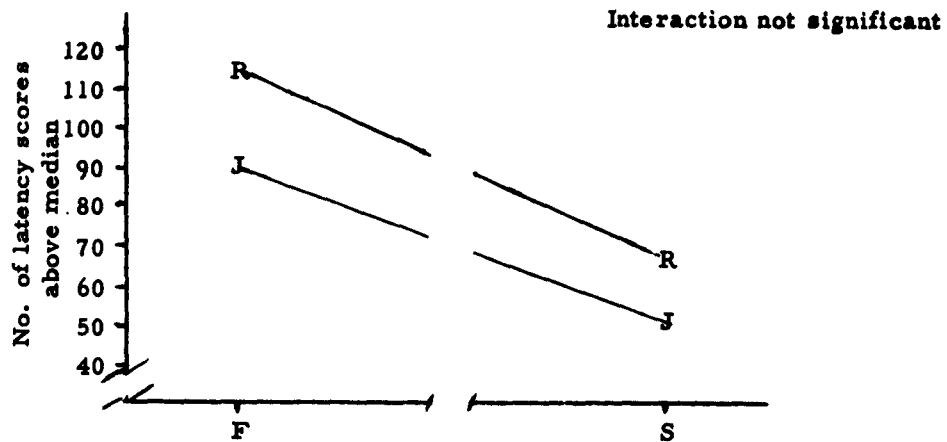


Figure 16. A x D interaction where R represents Reciprocating pilot, J = Jet pilot, F = Formation flight, S = Single aircraft flight.

Table 8

Nonparametric analysis of variance: formation vs. single aircraft flight, and jet vs. reciprocating pilots (effect on latency scores)

Source of variation	Chi sq.	df	Significance
A. Formation vs. Single Aircraft Flight	48.41	1	$p < .01$
D. Jet and Reciprocating Pilots vs. Reciprocating Only	11.03	1	$p < .01$
A x D Interaction	.40	1	NS

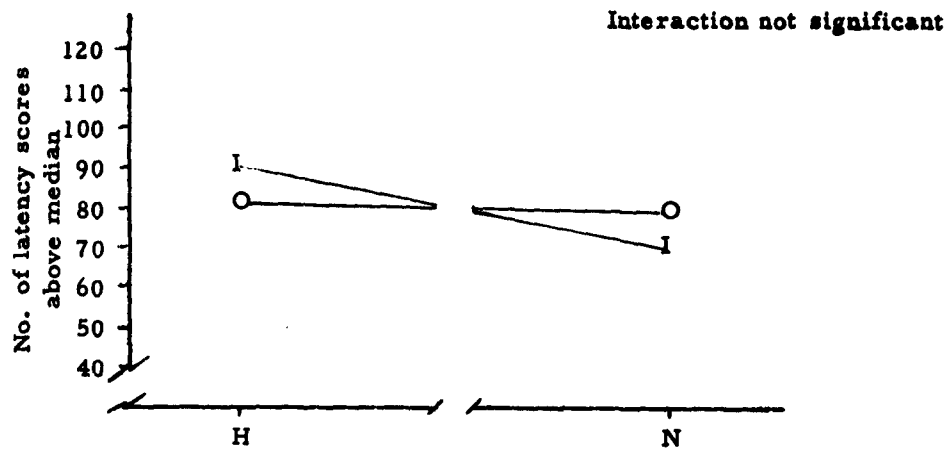


Figure 17. B x C interaction where I represents Inside cockpit emergencies, O = Outside cockpit emergencies, H = External visual horizon, N = No external horizon.

Table 9

Nonparametric analysis of variance: horizon vs. no horizon, and inside vs. outside emergencies (effect on latency scores)

Source of Variation	Chi sq.	df	Significance
B. External Horizon vs. No External Horizon	2.02	1	NS
C. Inside vs. Outside Emergencies	.02	1	NS
B x C Interaction	2.04	1	NS

some discussion.

Pilot types were differentially affected by the presence or absence of a horizon. This interaction was significant at the .10 level ( $p < .10$ ).

Figure 18 indicates that the jet pilots demonstrated fewer long latencies to emergencies under the no-horizon conditions than under horizon conditions. This is the reverse of what was predicted. The reciprocating pilots showed no latency score difference due to the presence or absence of a horizon. One explanation comes from the interview data in which many subjects reported difficulty in the use of the external horizon, because its contrast ratio was not great enough. Perhaps there was differential use of the horizon as a function of being either a jet or a reciprocating pilot, i. e., the jet pilots made more use of the external horizon than the reciprocating pilots. In perceptual terms, one might say that the horizon was not enough above threshold for normal use, and resulted in extra time spent on its proper utilization which could have been spent detecting emergencies.

To state the case still differently, the use of the external horizon interfered with the scan pattern of the jet pilots because they attempted to integrate this information to an extent which detracted from their performance. However, it must be pointed out that the jet pilots performed significantly better than the reciprocating pilots ( $p < .01$ ). This necessitates a within-jet pilot interpretation of the previous speculation, i. e., in terms of their actual performance compared with their potential performance.

-----  
(C X D) = Emergencies (inside vs. outside) X Pilot Type (Jet vs. reciprocating)

Although a significant interaction was not quite achieved, there were again some interesting trends (Figure 19). In the main effect of pilot types it was found that the jet pilots had a lower frequency of long latencies to the emergencies than the reciprocating pilots. This is of less interest than the apparent reversal of order in the plot (Figure 19). These apparent trends are of interest in that future research might yield significance. An interesting speculation follows:

Some jet pilots may do a better job of rapidly detecting outside cockpit emergencies whereas some reciprocating pilots may detect inside emergencies more rapidly. A possible explanation of this predicted difference within the jet group is as follows: the major concern of the jet pilots may be the avoidance of mid-air collisions, because of the high performance aircraft they normally fly, thus resulting in more scanning of the external world than the cockpit instruments.

The converse might hold true for the reciprocating engine pilots who

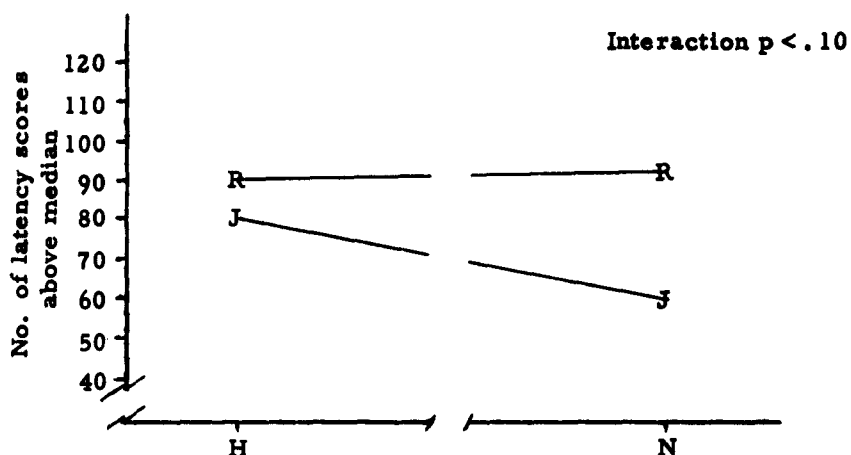


Figure 18. B x D interaction where R represents Reciprocating pilots, J = Jet pilots, H = External Horizon, N = No external horizon.

Table 10

Nonparametric analysis of variance: horizon vs. no horizon, and jet vs. reciprocating pilots (effect on latency scores)

Source of Variation	Chi sq.	df	Significance
B. External Horizon vs. No External Horizon	2.02	1	NS
D. Jet and Reciprocating Pilots vs. Reciprocating Only	11.03	1	$p < .01$
B x D Interaction	3.02	1	$p < .10$

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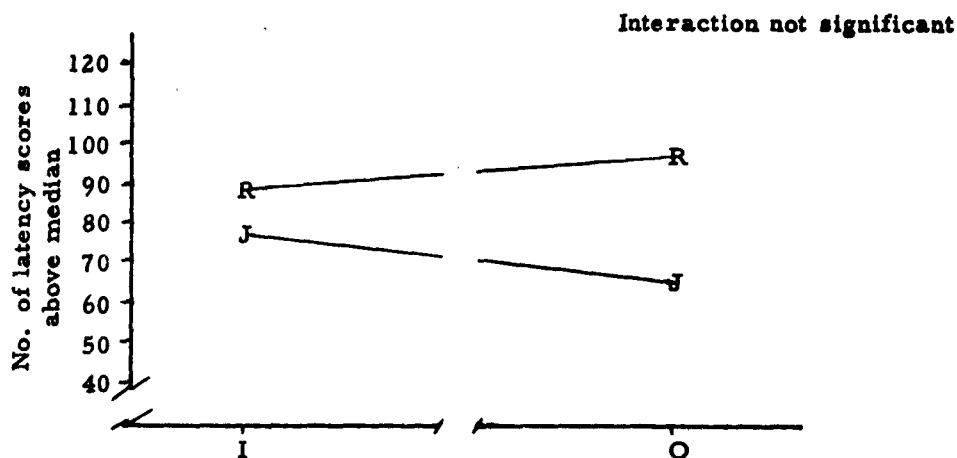


Figure 19. C x D interaction where R represents Reciprocating pilots, J = Jet pilots, I = Inside cockpit emergencies, O = Outside cockpit emergencies.

Table 11

Nonparametric analysis of variance: inside vs. outside emergencies, and jet vs. reciprocating pilots (effect on latency scores)

Source of Variation	Chi sq.	df	Significance
C. Inside vs. Outside Emergencies	.02	1	NS
D. Jet and Reciprocating Pilots vs. Reciprocating Only	11.03	1	$p < .01$
C x D Interaction	2.03	1	NS

are more accustomed to flying low speed aircraft where there is normally a greater time lag between the detection of a bogie and a course alteration to avoid a collision. Another possibility is that reciprocating pilots do more instrument flying thus giving them an inside cockpit orientation.

Perhaps the dependent variable used in the present study lacked sufficient sensitivity to detect these differences. The use of a head camera where the dependent variable would be frequency of visual fixations might yield significance.

f. Session Interactions. These will be viewed both as interactions and learning curves.

(A X E) = Conditions (formation vs. single aircraft flight) X Sessions

This represents one of our time-sharing interactions. As can be observed by an examination of the plot in Figure 20, there was quite rapid improvement in detecting emergencies under both the formation as well as the single aircraft conditions; however, performance under the formation conditions remained significantly poorer than in the single aircraft conditions. The authors are quite confident that with proper training this difference could be diminished to virtually nothing\*. The plot demonstrates the lack of proper time-sharing by a highly sophisticated group of pilot subjects and the need for just such training. The possibility of such training is supported by the significant improvement over sessions ( $p < .01$ ).

-----  
(B X E) = Conditions (horizon vs. no horizon) X Sessions

This also represents one of our time-sharing interactions. The plot graphically portrays (Figure 21) how the subjects' detection of emergencies improved with training under two different flight conditions, viz., horizon and no horizon.

The interaction was not significant. Again the non-significant difference between horizon vs. no horizon conditions must be interpreted with caution since many of the subjects reported initial non-use of the external visual horizon because of its low contrast ratio. For training purposes it might be advisable to have a greater range within which the horizon contrast ratio can be varied so that the contrast can be exaggerated unrealistically during an orientation period; this is because pilots are not accustomed to flying simulators with an external visual display.

-----  
(C X E) = Emergencies (inside vs. outside the cockpit) X Sessions

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\* The statement about the possibility of these differences being reduced is not tied to the data, and thus represents a speculation.

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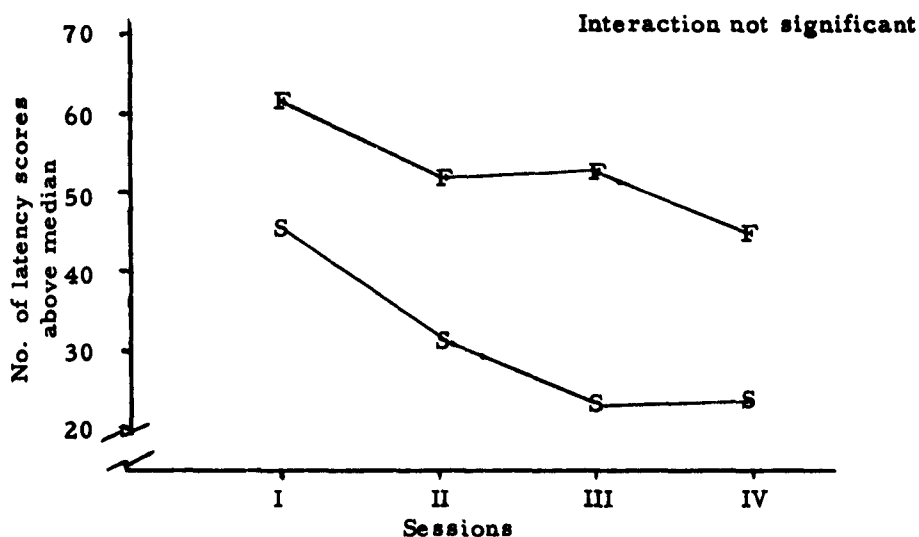


Figure 20. A x E interaction where F represents Formation Flight and S = Single aircraft flight.

Table 12

Nonparametric analysis of variance: formation vs. single aircraft flight, and sessions (effect on latency scores)

Source of Variation	Chi sq.	df	Significance
A. Formation vs. Single Aircraft Flight	48.41	1	$p < .01$
E. Sessions	23.23	3	$p < .01$
A x E Interaction	2.56	3	NS



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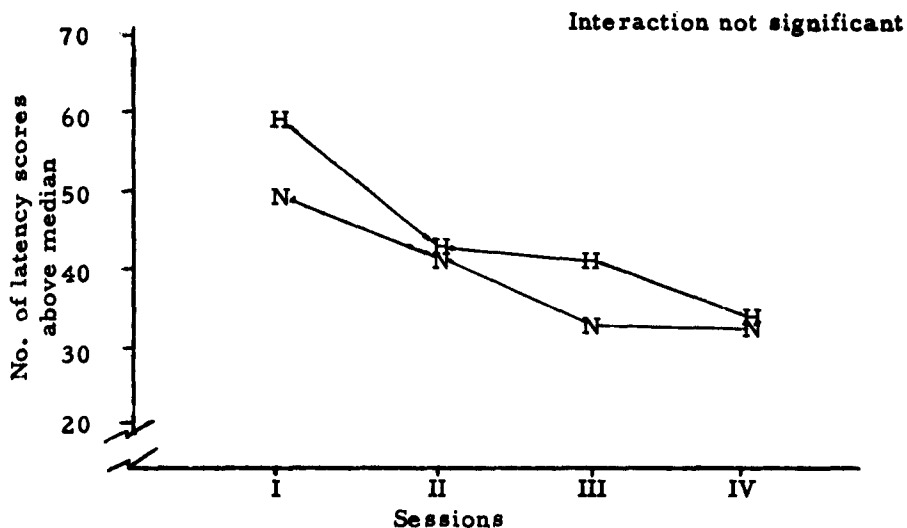


Figure 21. B x E interaction where H represents Flight with external horizon present, N = No external horizon.

Table 13

Nonparametric analysis of variance: horizon vs. no horizon, and sessions (effect on latency scores)

Source of Variation	Chi sq.	df	Significance
B. External Horizon vs. No External Horizon	2.02	1	NS
E. Sessions	23.23	3	$p < .01$
B x E Interaction	2.14	3	NS

A non-significant interaction was both expected and obtained as the integrated procedures training used and the initial equivalence of the two classes of emergencies would result in this same trend for both classes of emergencies as a function of sessions. This is not meant to imply that a significant main effect is the prerequisite for a significant interaction. Figure 22 demonstrates how the frequency of long latencies was initially high and then gradually reduced as a function of sessions.

The significant sessions effect supports our time-sharing hypothesis ( $p < .01$ ) in that there was a significant improvement in emergency detection behavior as a function of training sessions. The non-significant effect between inside and outside emergencies is also important in that time-sharing is two-fold: (1) the pilots should be able to handle emergencies outside and inside the cockpit with nearly equal facility\*, and (2) there should be an improvement in this behavior with training. Both of these are demonstrated in Figure 22.

-----  
(D X E) = Pilot types (jet vs. reciprocating) X Sessions

A non-significant interaction was both predicted and obtained. This prediction was based on the assumption that the skills required for piloting an aircraft are essentially the same regardless of type or mission (Figure 23).

There was no differential effect of training on pilot types.

## 2. ANALYSIS #2 (ALTITUDE DEPENDENT VARIABLE)

a. Conditions of Flight. For analysis purposes, this dimension was broken down as follows:

A = Formation vs. single aircraft flight

B = Horizon vs. no horizon

Selection of these four conditions was on the basis of maximizing the probability of the subjects' scan pattern being outside or inside the cockpit, as well as varying the over-all complexity of the task. Largely on these grounds a significant condition effect was both expected and obtained for both formation vs. single aircraft flight ( $p < .01$ ) and horizon vs. no external horizon ( $p < .10$ ). The subjects were able to hold altitude better (lower frequency of large deviations around 20,000 feet) while flying singly, as

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\* It must be pointed out that inside and outside emergencies were intentionally equated as to difficulty by the experimenters.

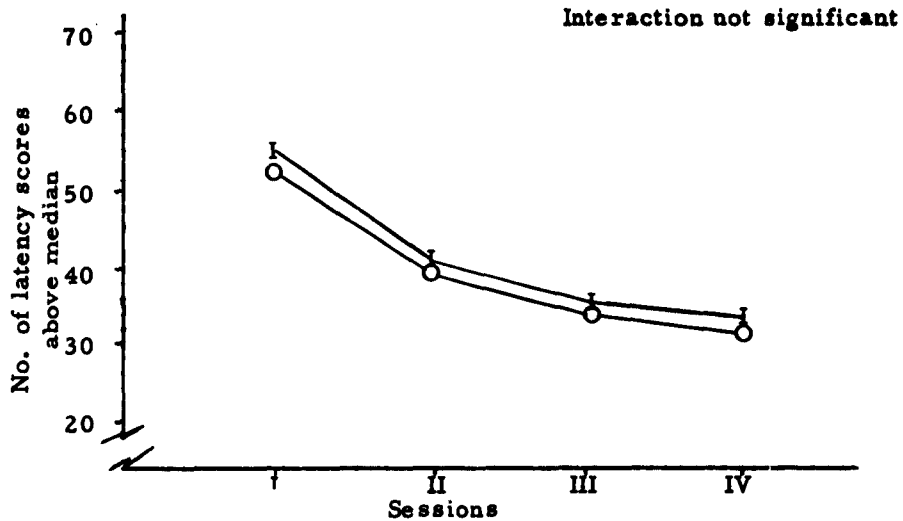


Figure 22. C x E interaction where I represents Inside cockpit emergencies, O = Outside cockpit emergencies.

Table 14

Nonparametric analysis of variance: inside vs. outside emergencies, and sessions (effect on latency scores)

Source of Variation	Chi sq.	df	Significance
C. Inside vs. Outside Emergencies	.02	1	NS
E. Sessions	23.23	3	$p < .01$
C x E Interaction	.23	3	NS

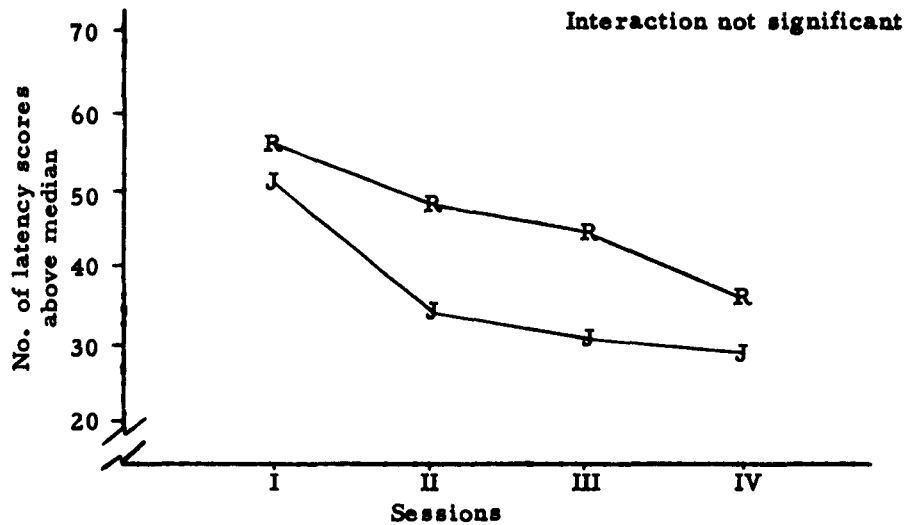


Figure 23. D x E interaction where R represents Reciprocating pilots, J = Jet pilots.

Table 15

Nonparametric analysis of variance: jet vs. reciprocating pilots, and sessions (effect on latency scores)

Source of Variation	Chi sq.	df	Significance
D. Jet and Reciprocating Pilots vs. Reciprocating Only	11.03	1	$p < .01$
E. Sessions	23.23	3	$p < .01$
D x E Interaction	1.92	3	NS

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Table 16

Summary of nonparametric analysis of variance  
effect of all conditions on latency scores

Source of Variation	Chi Sq.	df	Significance
A. Formation vs. single aircraft flight	48.41	1	p < .01
B. External horizon vs. no external horizon	2.02	1	N.S.
C. Inside vs. outside emergencies	.02	1	p > .90*
D. Jet and reciprocating pilots vs. reciprocating only	11.03	1	p < .01
E. Sessions	23.23	3	p < .01
A X B Interaction	.01	1	N.S.
A X C Interaction	4.91	1	p < .05
A X D Interaction	.40	1	N.S.
A X E Interaction	2.56	3	N.S.
B X C Interaction	2.04	1	N.S.
B X D Interaction	3.02	1	p < .10
B X E Interaction	2.14	3	N.S.
C X D Interaction	2.03	1	N.S.
C X E Interaction	.23	3	N.S.
D X E Interaction	1.93	3	N.S.

\* Relative to a significance criterion of .10 the difference was not statistically significant.

opposed to flying formation and the frequency of large altitude deviations was less when flying with an external horizon. The significantly inferior performance while flying formation might be explained in terms of the complexity of the task. Formation flying is definitely a more complex task than single aircraft flying. This was especially so in the present study because of the 2,000 feet lateral separation between wingman and formation leader and the simulated night conditions. A separation this great would not normally be maintained at night in a real-world situation. It is speculated that the subject's visual scan pattern was forced toward the formation leader only partly, with a resultant visual alternation. The above speculation is expounded below.

The pilots in our study had to use whatever visual cues were available for maintaining aircraft control in relation to the target aircraft, to a point where relative motion between the two aircraft averaged zero. It is thought that this visual alternation interfered with maintaining aircraft control. Assuming that the previous speculation is correct, then it would seem that a large part of good formation flying involves adequate visual time sharing, i.e., the ability to shift between references when needed. This is especially so during the join-up phase, when a gradual shifting of visual attention both between and within the available classes of visual cues is necessary. This sort of training could be given in a simulator such as the F-100/151.

The less variable performance with an external horizon as opposed to flying without the horizon is more difficult to explain. After an inspection of the data, this difference appears to have been largely due to one condition, viz., formation flying without an external horizon. This condition represented a situation wherein there were insufficient extracockpit visual cues for satisfactory performance of the task. To state the case differently, there was insufficient visual input for maintaining satisfactory aircraft control.

b. Type of Pilots. For analysis purposes, pilots were divided into two classes as follows:

D = Jet and reciprocating (n = 5) vs. reciprocating only (n = 5)

Although a significant pilot type effect was expected on the grounds that the testing equipment was a jet simulator, which might have favored those with jet experience, this effect was not found, i.e., there was no difference between jet and reciprocating pilots in their ability to hold altitude. This nonsignificance is particularly interesting in the light of the previous statement. Apparently, the reciprocating pilots (even with the situation biased against them) maintain as good aircraft control as the jet pilots. However, at this point it must be noted that the classification of the two groups of pilots into their respective categories was of necessity

arbitrary, as all of the jet pilots had prior or concurrent reciprocating engine flight time. This is also the most usual case in the jet pilot population. When aircraft control behavior (altitude variability data) is related to emergency detection behavior (latency data) for the two classes of pilots, the results become even more interesting. The emergency detection behavior is superior for jet pilots, but aircraft control proficiency of the reciprocating pilots was not significantly different from that of the jet pilots. One might speculate that the reciprocating pilots were more oriented in terms of aircraft control than emergency detection. Although this cannot be safely inferred from the data, it does represent a hypothesis worth testing. The results of just such a study would have important implications for the training of proper time-sharing behavior, as well as initial selection for different types of training.

c. Sessions.

E = Training Sessions 1 through 4

An over-all session effect was both expected and obtained ( $p < .05$ ), i.e., there was a significant improvement in maintaining altitude with increased practice. One would expect this improvement largely on the grounds that the subjects were all unfamiliar with the simulator, with the exception of one, who had had a half hour of orientation several weeks prior to the experiment. Thus, there should be an improvement in performance, or, in terms of the dependent variable measure, the frequency of large altitude deviations should decrease as a function of practice. When the high level of sophistication of the subjects is considered, an inference about the training potential of the F-100/151 becomes possible, i.e., apparently the simulator with its external visual display has potential for improving altitude holding performance in sophisticated subjects.

When sophisticated subjects are used, as in the present study, the experiment is biased against itself in that sophisticated subjects would be expected to improve less than naive subjects. Thus, one would expect that had naive subjects been used there would have been even more improvement.

d. Interactions.

(A X B) = Formation vs. single aircraft flight X horizon vs. no horizon

The four conditions and the reasons for using them are essentially the same as, and are presented with, Analysis #1. (Low scores mean good performance.)

A significant interaction was both expected and obtained ( $p < .05$ ). An inspection of Figure 24 demonstrates that this interaction was due to the

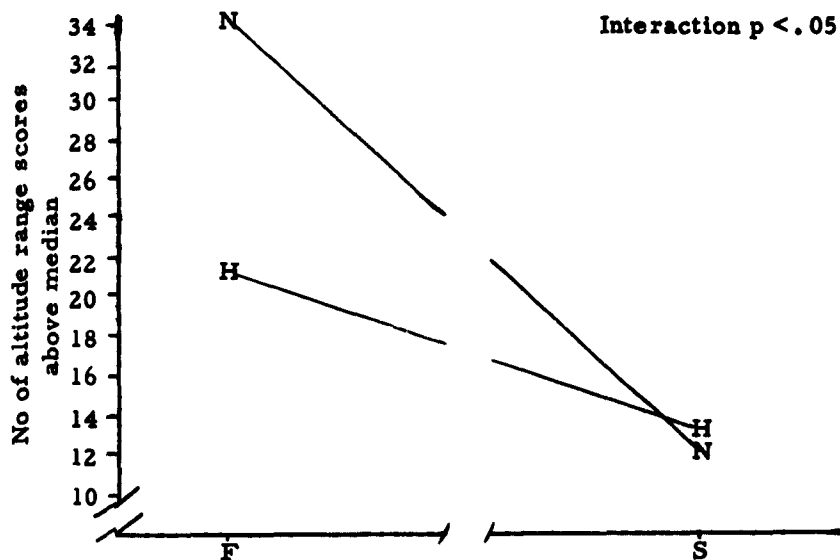


Figure 24. A x B interaction where F represents Formation flying, S = Single aircraft flying, H = Horizon present, N = No external horizon.

Table 17

Nonparametric analysis of variance: formation vs. single aircraft flight, and horizon vs. no horizon (effect on altitude holding)

Source of Variation	Chi sq.	df	Significance
A. Formation vs. Single Aircraft Flight	22.50	1	$p < .01$
B. Horizon vs. No External Horizon	3.60	1	$p < .10$
A x B Interaction	4.90	1	$p < .05$



conditions involving formation flying with and without an external horizon, i.e., the frequency of large altitude deviations was greater during formation flying without an external horizon than with the external horizon present. As has been stated in Analysis #1, the formation flying task without an external horizon represented a situation wherein the visual cues for its performance were inadequate. An analysis of the formation flying task will clarify the previous statement. Once the wingman has detected the target aircraft in space and has discriminated its position and range and identified it as his formation leader, the distance between the two aircraft must be gradually reduced to the point where the relative motion between the two aircraft averages zero. (Although data were collected only after join-up, the subjects had such difficulty that their behavior might be best described as joining and rejoining to maintain position.)

During the early stages of join-up with the target aircraft, it will appear to the wingman that the shape of the target is changing; size seems to grow slowly at first, then more rapidly during the later stages of closure. There will be increased resolution of detail with decreased distance; shadow patterns may change as the target aircraft changes its position relative to the sun. (The latter information was not available to the subjects in the present study, as night conditions were simulated.) The brightness of the aircraft changes with decreased distance due to atmospheric attenuation or aerial perspective. (This cue was also absent from the 151 visual display.) Related to this is the fact that any hues present may be more readily identified as range decreases (hue not present in the 151 visual display). Relative speed (while often indistinguishable at first) becomes increasingly obvious with decreased distance; this is also the case for acceleration. There is also a gradual shifting of the source of information for velocity and acceleration, i.e., initially the actual speed of the target aircraft is usually known (this was true in the present study), so that relative speed is judged by relating speed shown on the airspeed indicator of the interceptor with the known speed of the target. The same general statement holds for acceleration; however as the range decreases the source of this information comes less and less from the integration of information from the cockpit instruments with known target speeds and more and more from a visual judgment of the target in relation to the wingman.

There is also a similar shifting of the source of information to maintain aerodynamic stability, i.e., information needed for control of roll, pitch and yaw. At first the cues come from the cockpit instruments of the interceptor and from the external visual world. Among the external cues, the angle and elevation of the horizon on the windscreen is important for roll and pitch. (In the present study poorest aircraft control resulted when there was no external horizon.)

As the wingman approaches the formation leader, the scan pattern of

the wingman is forced out of the cockpit to an increasingly greater extent, i.e., he refers less to his cockpit instruments and more to the external horizon (if present) and the target aircraft. Still later during the closure or join-up task it is speculated that there is a shifting of attention even within the cues from the external world, i.e., the horizon (if present) becomes less important for pitch and roll information as the target aircraft provides this information during close formation. (In the present study there was 2,000 feet lateral separation between wingman and formation leader.) Thus it is speculated that there is initial alternation between inside and outside cockpit cues, later only alternation within outside cockpit cues, and finally only the target aircraft is scanned.

Assuming that the above analysis is correct, then it would seem that at least a large segment of good formation flying involves good time sharing, i.e., the ability to shift between visual references when needed. This is especially true during the join-up phase when a gradual shifting of visual attention, both between and within the available classes of visual cues (outside and inside the cockpit) is necessary. This sort of training could be given in a simulator such as the F-100/151.

-----  
(A X D) = Conditions (Formation vs. single aircraft flight) X Pilot Type (jet vs. reciprocating)

A significant interaction was expected but not obtained. The expected interaction was largely on the grounds that some of the conditions on an a priori basis appeared to be more favorable to the jet pilots than the reciprocating pilots. This appeared especially true for the formation tasks. Figure 25 illustrates this interaction.

The obvious interpretation of this interaction is that the type of flight experience (for sophisticated pilots) has little to do with performance in the F-100/151 jet simulator under the conditions tested; however, the reader must be reminded that the subjects were not equated initially and the classification of pilot types was necessarily arbitrary. One possible implication of this finding is that F-100/151 needs improvement along one or several dimensions, so that jet and reciprocating pilots are distinguishable in terms of their altitude holding performance. Another possible explanation is that the reciprocating pilots were very much oriented toward maintaining aircraft control and thus over-achieved. Still another possibility is that the classification of the subjects as to pilot type was erroneous due to excessive overlap in experience. Another possibility is that altitude holding ability is readily transferable across types of aircraft.

-----  
(B X D) = Conditions (Horizon vs. no external horizon) X Pilot Type (jet vs. reciprocating)

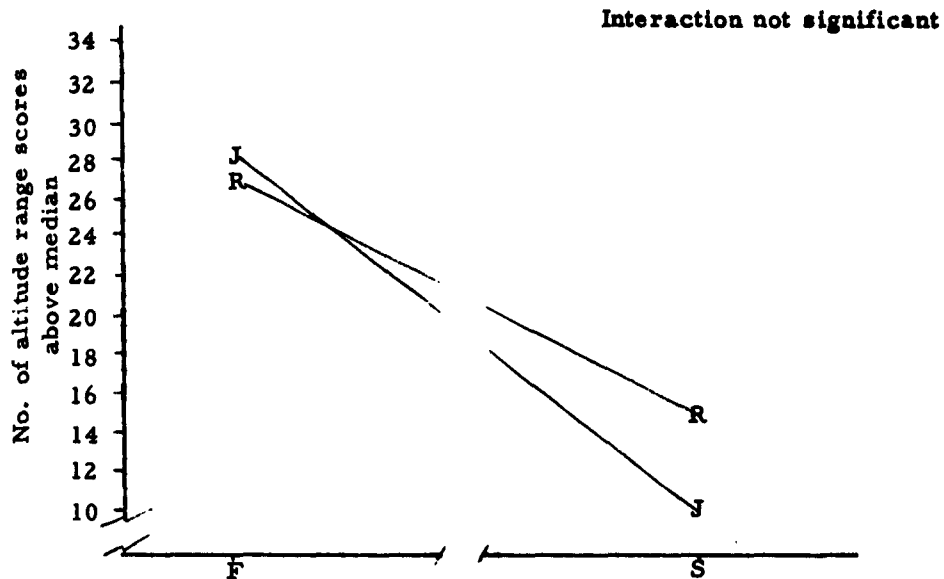


Figure 25. A x D interaction where F represents Formation flying, S = Single aircraft flying, J = Jet pilots, R = Reciprocating pilots.

Table 18

Nonparametric analysis of variance: formation vs. single aircraft flight, and jet vs. reciprocating pilots (effect on altitude holding)

Source of Variation	Chi sq.	df	Significance
A. Formation vs. Single Aircraft Flight	22.50	1	p < .01
D. Jet and Reciprocating Pilots vs. Reciprocating Only	.40	1	NS
A x D Interaction	.90	1	NS

The interaction obtained was not significant (Figure 26); however, of some interest is the comparison of this interaction with that obtained using the latency dependent variable. In the latter (Figure 18), the jet pilots apparently performed best under the no horizon conditions, whereas the reciprocating pilots performed the same under both horizon and no horizon conditions (emergency detection behavior). In the former (aircraft control behavior) the performance of these two classes of pilots was quite parallel under the above-mentioned conditions, but with subjects (pilots) pooled, the horizon condition resulted in superior performance. Thus jet pilots apparently performed better under no external horizon conditions in terms of emergency detection behavior, but poorer under no external horizon conditions in terms of aircraft control. Since time sharing involves both emergency detection behavior and aircraft control, this differing emphasis on the part of jet pilots, as a function of horizon-no horizon conditions when separate dependent variable measures are compared, warrants further investigation, preferably with the head camera. It is believed that this approach would enable isolation of the variables involved.

e. Session Interactions. These will be viewed both as interactions and learning curves.

(A X E) = Conditions (formation vs. single aircraft flight) X Sessions

A significant interaction or a non-significant interaction could have supported our time-sharing hypothesis, depending on the relation of performance during the early sessions with the later session. Figure 27 illustrates this interaction, which was not significant.

A significant interaction would have been unusual in that formation flying is considered an inherently more complex task than single aircraft flying. The most important result that can be inferred from the plot is that there is a significant improvement ( $p < .05$ ) in performance. This leads to the conclusion that the F-100/151 has potential for training (in an integrated fashion) sophisticated pilots to improve their altitude holding performance. This conclusion probably could also be extended to naive pilots in that even more improvement would be possible.

The formation vs. single aircraft condition was also significant ( $p < .01$ ).

-----  
(B X E) = Conditions (Horizon vs. no external horizon) X Sessions

A significant interaction was not obtained; however, horizon vs. no external horizon was significant ( $p < .10$ ) and there was also a significant session effect ( $p < .05$ ). The significant difference between horizon-no horizon must be interpreted with caution, as many of the subjects reported

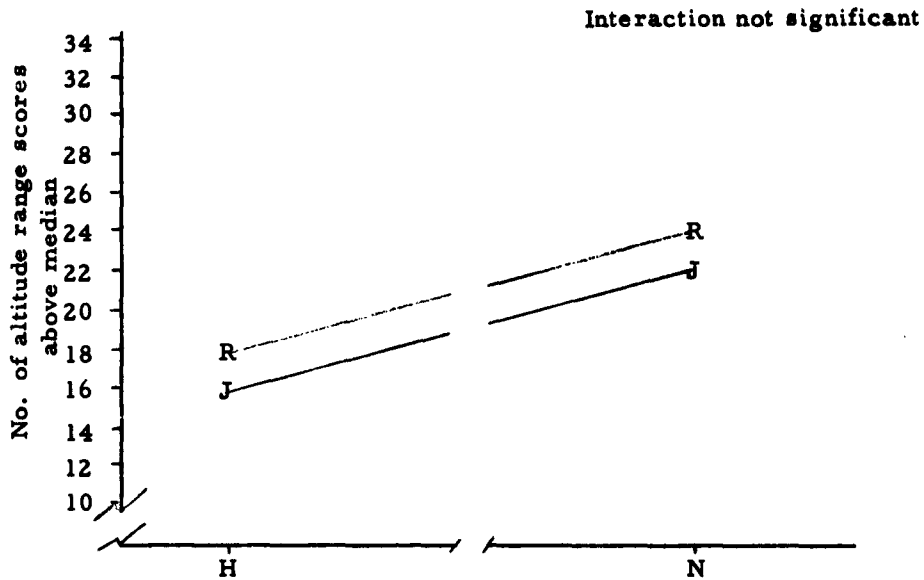


Figure 26. B x D interaction where R represents Reciprocating pilots, J = Jet pilots, H = Horizon, N = No horizon.

Table 19

Nonparametric analysis of variance: horizon vs. no horizon, and jet vs. reciprocating pilots (effect on altitude holding)

Source of Variation	Chi sq.	df	Significance
B. Horizon vs. No Horizon	3.60	1	$p < .10$
D. Jet and Reciprocating Pilots vs. Reciprocating Only	.40	1	NS
B x D Interaction	.00	1	NS

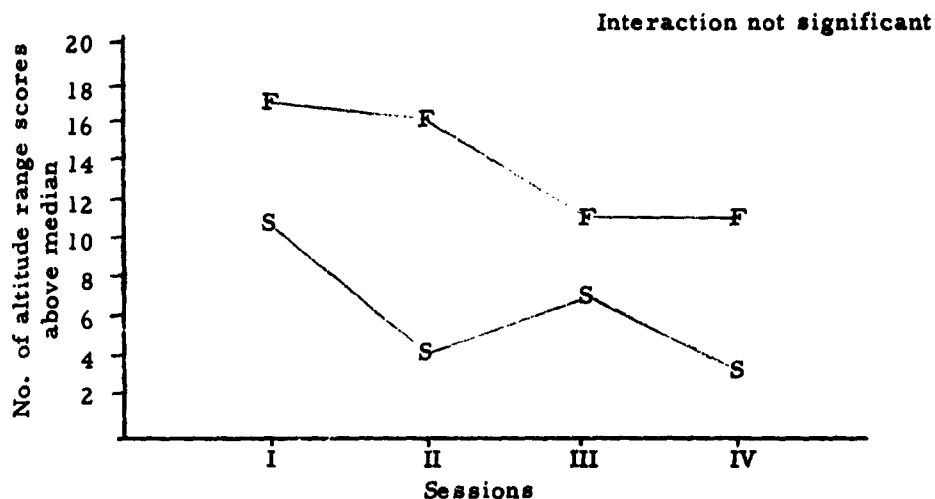


Figure 27. A x E interaction where F represents Formation conditions, S = Single aircraft conditions.

Table 20

Nonparametric analysis of variance: formation vs. single aircraft flight, and sessions (effect on altitude holding)

Source of Variation	Chi sq.	df	Significance
A. Formation vs. Single Aircraft Flight	22.50	1	$p < .01$
E. Sessions	10.40	3	$p < .05$
A x E Interaction	3.50	3	NS

initial non-use of the external horizon.

The most important outcome of this analysis is the improvement of altitude holding with training sessions. This is illustrated in Figure 28.

Another interesting finding is that the horizon-no horizon conditions differed significantly ( $p < .10$ ) for the altitude dependent variable, but not for the latency dependent variable. Apparently the presence or absence of an external horizon made no difference (with latency scores pooled) in emergency detection behavior, but did make a difference in terms of aircraft control (Figure 21 and Figure 28). However, it must be pointed out that some of the subjects reported initial non-use of the external horizon due to its low illumination as well as its low contrast ratio.

-----  
(D X E) = Pilot Type (jet vs. reciprocating) X Sessions

This interaction was not significant and represents what was expected. One can assume that the skills required for maintaining aircraft control in the F-100/151 simulator are essentially the same regardless of the particular background (jet vs. reciprocating) of the subjects\* in question. The overlapping in the curves represents chance variation (Figure 29). The important conclusion is that both jet and reciprocating pilots improved with training ( $p < .05$ ). The non-significance between pilot types has been discussed under simple effects.

### 3. ANALYSIS #3 - CORRELATIONAL MEASURES.

a. Rank order coefficient of correlation between pilot flying hours and latency to respond to emergencies.

$$r_s = -.60 (p < .10)**$$

$$n = 10$$

One would expect that those pilots with most experience would tend to rank highest in emergency detection behavior. Actually, the reverse was found. The obvious interpretation would be that the amount of experience is less important than the type of experience in flying the F-100/151 simulator. This is borne out by the fact that closer inspection of the subjects' experience records revealed that those with jet experience had fewer flying hours than those with reciprocating engine experience only; however, the jet experience was presumably more relevant to the experimental task.

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\* The subjects used in the present study.

\*\* Two tail test using Student's t.

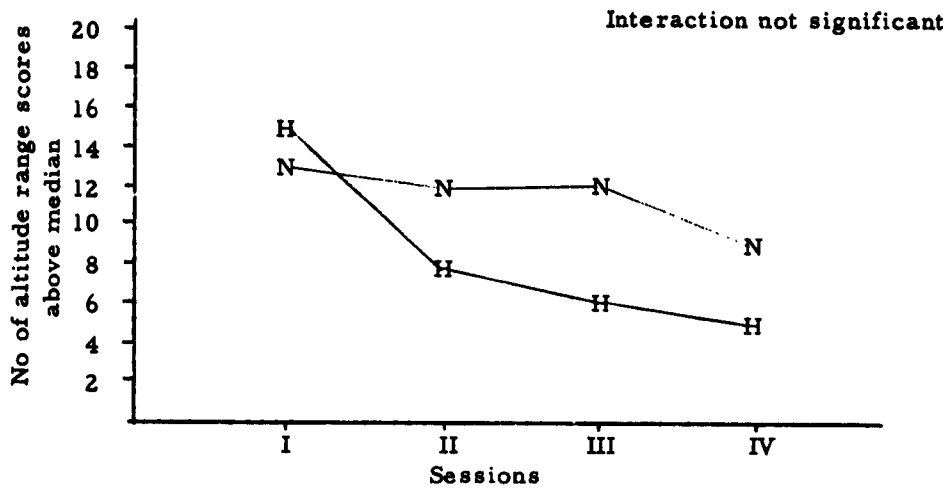


Figure 28. B x E interaction where H represents Horizon conditions, N = No external horizon conditions.

Table 21

Nonparametric analysis of variance: horizon vs. no horizon, and sessions (effect on altitude holding)

Source of Variation	Chi sq.	df	Significance
B. Horizon vs. No External Horizon	3.60	1	$p < .01$
E. Sessions	10.40	3	$p < .05$
B x E Interaction	3.60	3	NS



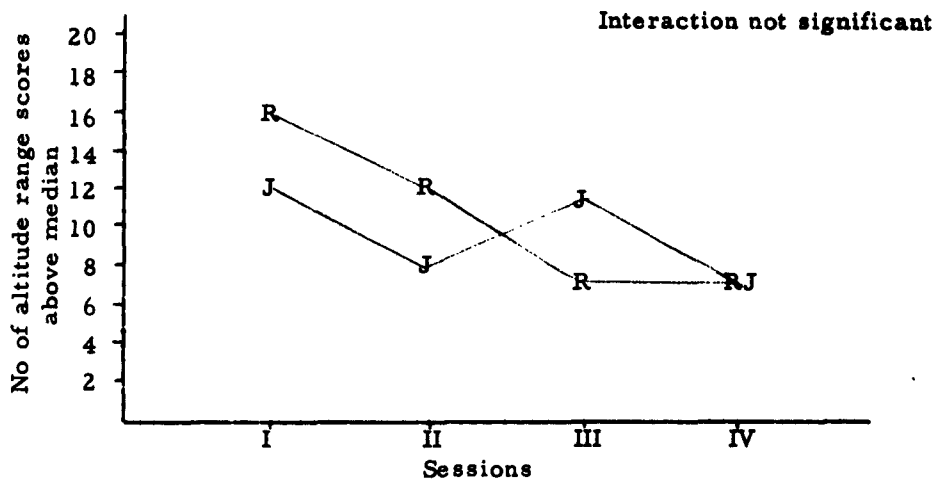


Figure 29. D x E interaction where J represents Jet pilots, R Reciprocating pilots.

Table 22

Nonparametric analysis of variance: jet vs. reciprocating pilots, and sessions (effect on altitude holding)

Source of Variation	Chi sq.	df	Significance
D. Jet and Reciprocating Pilots vs. Reciprocating Only	.40	1	NS
E. Sessions	10.40	3	$p < .05$
D x E Interaction	4.40	3	NS

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Table 23

Summary of nonparametric analysis of variance:  
effect of all conditions on altitude holding

Source of Variation	Chi sq.	df	Significance
A. Formation vs. single aircraft flight	22.50	1	p < .01
B. Horizon vs. no external horizon	3.60	1	p < .10
D. Jet and Reciprocating pilots vs. reciprocating only	.40	1	N.S.
E. Sessions	10.40	3	p < .05
A X B Interaction	4.90	1	p < .05
A X D Interaction	.90	1	N. S.
A X E Interaction	3.50	3	N.S.
B X D Interaction	.00	1	N.S.
B X E Interaction	3.60	3	N.S.
D X E Interaction	4.40	3	N.S.

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b. Rank order coefficient of correlation between pilot flying hours and altitude holding performance.

$$r_s = -.03$$

$$n = 10$$

Hence, there was no relation between the amount of pilot experience and ability to hold an assigned altitude under the present experimental conditions in the F-100/151 simulator. Perhaps the range was restricted because of the high level of sophistication of the subjects.

c. Rank order coefficient of correlation between emergency performance and altitude holding performance.

$$r_s = +.12$$

$$n = 10$$

This lack of relationship was not at all expected and thus warrants some discussion. One might have predicted that the pilots who performed best in terms of emergency behavior would also have performed best in terms of aircraft control. However, this was not the case. The lack of relationship may be used to support the contention that the sophisticated subjects in our sample need time-sharing training, i.e., the simulator must teach time-sharing between visual cues (emergency detection) and the perceptual motor skill (altitude holding). Highly skilled performance in the former is not related to highly skilled performance in the latter.

The lack of good time-sharing as evidenced by the sophisticated subjects in the present study has implications for the need for just such training in naive subjects. Although such inferences are usually made with some hesitancy, we feel they are justified under the present circumstances.

## G. CONCLUSIONS

### 1. ANALYSIS #1.

#### a. Simple effects (latency dependent variable).

1) There was definitely a greater frequency of latency scores in excess of 13.76 seconds under the formation conditions.\* This is believed to be largely a function of the complexity of the task. Single aircraft flying resulted in better performance.

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\* 13.76 seconds represents the grand median detection time.

2) The addition of the external visual horizon had no over-all effect on emergency detection behavior. This is believed to be largely due to the inadequate contrast ratio and general illumination level.

3) With all other dimensions pooled, there was no difference between inside and outside emergency detection behavior, i.e., the frequency of scores above the median (13.76 seconds) was essentially the same.\* This is interpreted to mean that the inside and outside emergencies were successfully equated.

4) The jet pilots were superior in terms of emergency detection behavior. Pilot-type differences were very evident throughout the study. In general, jet pilots had fewer long detection times to emergencies (in excess of 13.76 seconds) than the reciprocating pilots.

5) The subjects improved their performance with training. This is interpreted to mean that the F-100/151 has potential for improving performance in emergency detection behavior (visual time-sharing).

b. Interactions (latency dependent variable).

6) Emergency detection during formation and single aircraft flying was not differentially affected as a function of the presence or absence of an external horizon. This is mitigated by the fact that some subjects reported initial non-use of the external horizon.

7) Detection times for emergencies (both inside the cockpit and outside the cockpit) were differentially affected as a function of flying singly or in formation. While flying singly there was a lower frequency of latency scores in excess of 13.76 seconds (good performance) than while flying formation. This is interpreted to mean that there is a need for time-sharing training.

8) There was no differential effect of pilot type on emergency detection during formation and single aircraft flying, i.e., the trend was the same for both pilot types.

9) There was no differential effect of horizon vs. no horizon conditions on the type of emergencies (inside vs. outside the cockpit). This is interpreted to support our contention that both the contrast ratio as well as the general level of illumination of the external horizon should be increased.

10) There was a differential effect on emergency detection behavior

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\* Relative to a significance criterion of .10, this difference was not statistically significant.

under horizon vs. no horizon conditions as a function of pilot type, i.e., jet pilots seemed to perform best under no external horizon conditions, whereas this difference was not found for reciprocating pilots.

11) The subjects improved their performance with training for the different conditions of flight as well as the different classes of emergencies. This is interpreted to mean that the F-100/151 has training potential for teaching visual time-sharing.

## 2. ANALYSIS #2.

### a. Simple effects (altitude dependent variable).

1) The subjects maintained better aircraft control while flying singly as opposed to flying formation. This may be interpreted in support of the F-100/151 as a training device.

2) The subjects maintained better aircraft control when the external horizon was present than when it was absent. This difference would probably increase with an improved horizon.

3) No differences were found as a function of pilot type. Apparently jet and reciprocating pilots did not differ in terms of altitude holding performance.

4) There was an over-all improvement in maintaining aircraft control (fewer deviations of altitude range scores in excess of 750 feet)\* with increased training. This is interpreted to mean that the F-100/151 has potential for teaching perceptual-motor time-sharing.

### b. Interactions (altitude dependent variable).

5) The presence or absence of an external horizon is differentially important as a function of flying in formation or singly, i.e., the presence of a horizon when flying in formation is much more important for maintaining aircraft control than when flying singly. This will be interpreted in support of the need for integrated procedure training.

6) Types of pilots are not differentially affected in terms of aircraft control as a function of flying singly or in formation.

7) There was an improvement in performance for the subjects with increased training under the different conditions. This is interpreted to mean that the F-100/151 has potential for teaching perceptual-motor time-sharing.

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\* This represents the median range of altitude deviations.

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3. ANALYSIS #3. Aircraft control behavior and emergency detection behavior were not related for the subjects used in the present study. Training to correct this is believed to be necessary by the authors.
4. GENERAL CONCLUSION. The time-sharing study using the F-100/151 fixed gunnery trainer reflects the need for proper time-sharing training as well as the possibilities for just such training in the same simulator with the improved horizon previously suggested.

### Summary of Logic for the Conclusions

In this study we were concerned with pilot performance in the F-100/151 jet simulator. More specifically, attention was directed to that characteristic of the pilot's visual scan pattern which we have called visual time-sharing. Accordingly, the subjects' task was so structured that while carrying out a simulated flight, three specific aspects of time-sharing behavior were called for:

- (a) inside cockpit scanning (cockpit emergency detection)
- (b) inside-outside cockpit scanning (formation flying)
- (c) outside cockpit scanning (intruder detection)

Latency to respond and deviation from prescribed altitude were measured.

It was assumed that since time-sharing is an essential element in reducing latency and maintaining altitude, an improvement in this performance would indicate improvement in time-sharing behavior.

### Results

The overall results of the study indicate improvement in performance on the simulator with practice, both with respect to emergency/intruder detection and aircraft control.

### Conclusions

It was therefore concluded that time-sharing behavior did improve with practice in the simulator. Since this improvement was general, improvement in one aspect of visual time-sharing apparently did not occur at the expense of performance in the other aspects. Since visual time-sharing is an essential element of the pilots' flight task and this behavior improved with practice,

even with experienced pilots, it was concluded that: (1) training in time-sharing can be effected; and (2) that the flight simulator constitutes a promising technique for implementing such training.

Qualification

In good conscience, a researcher must question whether improved visual behavior in the simulator necessarily results in such improvement in the aircraft. As to this question we have no direct confirmation. However, the opinions of experienced pilots indicate an expressed similarity between the simulated and real tasks. Furthermore, inducement of vertigo and other flight sensations in pilots in this simulator tends to reinforce the conclusion that considerable likeness exists between the simulated and real tasks.



EXHIBIT 1

RADIO COMMUNICATIONS

The following represents the actual radio communications that occurred during one entire session of the time-sharing study between the following people:

IC: Intercept Controller  
TC: Tower Controller  
P: Pilot

The session began at 12 noon.

12:00 TC: "151 from Atlantic City Tower, 151 is cleared to taxi to runway 31; Wind down the runway at 5 knots; altimeter 29.92."

P: "151, Roger 31; altimeter 29.92."

P: "Atlantic City Tower this is Navy 151 ready for takeoff."

TC: "Navy 151 is cleared to takeoff on runway 31; climb to 20,000 feet on heading 310 degrees; report reaching 20,000."

P: "This is 151, understand clear for takeoff; I'm on heading of 310; report 20,000 feet."

TC: "That is correct."

12:05

12:07 TC: "151 go right to heading 360 degrees, over."

P: "This is 151; understand right to heading 360."

P: "This is 151; steady 360."

TC: "151"

12:10 TC: "151 go left to 270 degrees and hold that heading."

P: "Left 270; roger."

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TC: "151 reduce airspeed to 350 knots."

P: "151, roger."

P: "151 windshield overheat."

TC: "51"

P: "151 Bogie at 11 o'clock or 9, 10 o'clock high."

TC: "51"

TC: "151 go left 090 degrees and hold that heading; reduce airspeed in turn from 350 knots to 300 knots; use your speed brakes."

P: "151, roger left to 090 degrees."

12:15

12:16 P: "Steady 090 degrees; speed 300."

TC: "Roger 151; increase speed to 350 knots indicated, holding heading 090 degrees."

P: "Roger; increase in speed to 350 knots."

12:17 P: "151 inverter failure."

TC: "51"

12:18 P: "This is 151; I have a Bogie at ah, about 2 o'clock high."

TC: "51"

TC: "151 go left to heading 360 degrees and hold that heading."

P: "Left at 360 degrees, roger."

12:20 P: "Heading 360 degrees."

TC: "51"

12:21 P: "This is 151; a Bogie at, ah, 11 o'clock high."

TC: "51"

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12:22 P: "151 target at, ah, 9 o'clock level."

TC: "Ah, roger 151 intercept target as if joining up in formation on the starboard side of the target; maintain 2,000 feet lateral separation and the same altitude as the target. At the present you have a 50 knot speed advantage on the target."

12:23 IC: "Present range 2,500 feet."

IC: "Range increasing slightly; 2,800 feet, 3,000 feet. Range increasing very fast now; 4,000 feet, 4,500 feet. Increase airspeed to 310 knots."

P: "Target's behind me."

IC: "Ah, roger, ah, retract speed brakes in and increase speed to 320 knots."

12:25 TC: "151 go left to 360 degrees."

P: "360 degrees."

IC: "Ah, 151 the target is presently holding 350 knots indicated."

P: "This is 151, roger, that's my speed."

IC: "Present range 5,000 feet."

12:29 TC: "151 target will now go right to 180 degrees. Remain on inside of turn with 2,000 feet lateral separation and attempt to hold your altitude, over."  
1/2

P: "151, roger."

IC: "Ah, roll out and hold steady for loss."

P: "151"

IC: "Increase airspeed to 310 knots."

P: "151 roger. He keeps, ah, going ahead of me, ah, if I, ah, get that fast. Or actually, he gets, keeps falling behind me."

IC: "Crank in a turn."

TC: "151, steady out on 180 degrees."

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P: "151"

P: "Target 2 o'clock."

TC: "151, ah, attempt to maintain your 2,000 feet lateral separation."

IC: "Present range 1,800 feet,"

P: "Having inverter failure."

TC: "51"

IC: "Range now increasing; 2,200 feet, 2,500 feet; range now holding fairly constant 2,900 feet. Range now decreasing slightly 2,500 feet. Decreasing very fast now 2,000 feet; 1,500 feet. Range now increasing very fast 2,500 feet."

12:35 TC: "151, target will now go left to 09. Correction, will go left to 360 degrees. You remain on inside of turn with 2,000 feet lateral separation and attempt to hold altitude."

P: "151 roger."

IC: "Present range 3,000 feet. Holding 3,000 feet. Range now decreasing slightly, 2,800 feet."

IC: "Range now holding constant 2,500 feet. Range now decreasing 2,200 feet, 2,000, 1,800. Range now holding 1,800. Range decreasing very slow 1,700; now holding 1,700; holding very nice. Range now increasing slightly; 1,800; 1,900; 2,000. Range now increasing very fast; 2,500, 3,000, 3,500. Range holding constant 3,500."

IC: "Range holding constant 3,500."

IC: "Range now decreasing slightly 3,300."

IC: "Holding fairly constant 3,300."

TC: "Ah, roger 51."

TC: "Now 151, target has now rolled out on 360 degree heading."

P: "Roger 360."

IC: "Present range 5,000 feet pulling away very fast."

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TC: "Now 151 hold heading 360 degrees."

P: "Roger 360."

P: "Another inverter failure."

TC: "51"

TC: "151 go left to heading of 270 degrees and hold that heading."

P: "270 roger."

P: "Generator out."

TC: "51"

P: "Also my power inverter."

TC: "Switch your generator to the on position."

12:40 P: "Roger"

P: "270"

TC: "Roger"

P: "I have a Bogie at 3 o'clock."

TC: "51"

TC: "151 go right to heading 090 degrees. Hold that heading; reduce speed in a turn to 300 knots indicated; use your speed brakes."

P: "Roger. Going right to 090 reducing airspeed to 300."

12:43

12:44 TC: "151 increase speed to 350 knots indicated. Hold heading 090 degrees. Switch secondary bus tie in the normal position."

P: "This is 151, roger, 090, 350 knots."

12:48 P: "This is 151. I got a Bogie at 3 o'clock high."

TC: "51"

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TC: "151, go left to heading 360 degrees."

P: "Left at 360."

12:52 P: "151 has got a target at 3 o'clock high."

TC: "51"

P: "151's got a target 10 o'clock; same altitude."

TC: "Ah, roger 151. At present you have almost 100 knots in excess of that of the target. Intercept target as if joining up in formation on the starboard side of the target. Maintain 2,000 feet lateral separation and the same altitude as the target."

P: "51 roger."

IC: "Range 5,000; range 5,000 holding steady; 5,000 holding steady; range 5,000 increasing slightly; range 6,000 increasing slightly."

TC: "51 increase your airspeed to about 350 knots."

12:54 IC: "Increasing slightly."

IC: "Range 6,000 holding steady; range decreasing 5,000; range decreasing slightly; range decreasing 4,000; range decreasing."

TC: "151 target will now accelerate to 350 knots indicated."

IC: "Range 2,800 decreasing; 2,500 decreasing range; decreasing 2,500; range decreasing. It is now 2,000; range holding steady at 2,000; holding steady at 2; range slightly increasing."

P: "Roger, I've had a hydraulic failure and I can't get my dive brakes."

IC: "Range is 2,500."

IC: "Range increasing."

P: "Hydraul---inverter failure."

Simultaneous

IC: "Range increasing 3,000."

TC: "51"

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IC: "Range increasing 3,500."

P: "Bogie high."

TC: "51 roger."

IC: "Range holding constant 3,000; range decreasing; 2,500 feet; range decreasing 2,300 feet; range 2,000."

P: "151 roger. I got another hydraulic failure."

TC: "51"

IC: "Range decreasing 1,000 feet; holding steady at 1,000."

TC: "151 target will not go right to 180 degrees; remain on inside of turn with 2,000 feet lateral separation and attempt to hold altitude."

IC: "Range 2,000 feet."

12:58 P: "151 roger."

IC: "Range holding at 1,800; range decreasing 1,500 feet; range decreasing 1,200 feet. Holding well at 1,200; 1,300, 14, 150 feet; range increasing 2,000; range increasing 2,500 feet; range 3,000 feet holding steady at 3,000; decreasing. Range decreasing 2,500 feet; range decreasing; 2,000 feet; Range holding at 2,000; range decreasing slightly to 1,500."

TC: "151 target now rolling out on 180 heading."

1:00 IC: "Range 1,500 increasing slightly; range 2,000 feet increasing."

P: "Target on my, ah, 1 o'clock position."

TC: "Ah, roger, 151 attempt to maintain your 2,000 feet lateral separation and hold altitude."

IC: "Range decreasing 1,500; range decreasing 1,000; range decreasing 500; range is 0."

P: "Was that target supposed to be in a turn?"

TC: "Negative; the target is holding steady on 180 degrees."

IC: "Range 700 feet increasing."

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P: "Roger. I don't have him in sight. I was in a steep turn to stay out of running over him."

TC: "Roger"

IC: "Range increasing 2,000 feet."

TC: "Ah, roger, 151. Do you have the target in sight now?"

P: "No, I have him at 3 o'clock position, 2 o'clock position."

IC: "Range increasing 3,000; holding steady at 3,000; decreasing slightly 2,500 feet; range decreasing 1,500 feet; range decreasing 1,000; holding steady at 1,000."

TC: "151, target will not go left to 090 degrees. You remain on inside of turn with 2,000 feet lateral separation and attempt to hold altitude."

P: "This is 151 roger. The same thing happened. He ran right in front of me. Ah, I was steady at 180. Now I have him at 1 o'clock."

TC: "Ah, roger."

IC: "Range 3,500 feet; 4,000; holding steady at 4,000; holding steady at 4,000 feet; range decreasing 2,500 feet; holding steady at 2,300 feet; decreasing slightly 2,000."

TC: "151, target has rolled out 090 degrees."

1:05 IC: "Range increasing 3, 2,500, 3,000, 3,500, 4,000 feet. Holding steady at 4,000; range decreasing slightly; range decreasing 2,500 feet."

TC: "151 from Atlantic City here, request you retard throttle, speed brakes down, and gear down for a high step out."

P: "151"

1:05 - Finished  
1/2



EXHIBIT 2

QUALITATIVE ANALYSIS OF INTERVIEW DATA  
AND EXPERIMENTER OBSERVATIONS

- 1) External Horizon
  - A) Subject comments varied between horizon too sharp and well defined to its being too vague and difficult to use.
  - B) Most typically the subjects found the horizon too difficult to be used in contact flight.
  - C) External horizon was used most frequently during formation task.
  - D) An interesting complaint a few people made was that horizon appeared to be too close, i. e. , the actual, not the imaginary (infinite) distance was seen.
- 2) Target Aircraft (TV Bogie)
  - A) Some reported the lack of additional references on target aircraft, e. g. , no navigation lights.
  - B) Some reported lack of cues for depth perception as related to join-up.
  - C) Some difficulties detecting relative movement. When the pilot "banked" his aircraft the formation leader appeared to zoom unrealistically about the sky. All movement was referred to the other aircraft.
  - D) Target aircraft appeared too bright.
  - E) Target can be seen at greater ranges--perhaps due to the lack of atmospheric attenuation.
- 3) Color - of those who reported lack of color, none thought it detracted from realism.
- 4) Flight Instruments
  - A) Grouping reported as poor - grouping actually was not typical for Naval aircraft, e. g. , airspeed indicator was upper left instead of closer to the flight instruments.

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5) Movement Sensations (associative imagery)

Most pilots actually hallucinated seat-of-the-pants cues.

A) Turning sensations more likely with external horizon (labyrinth stimulation).

B) Even "g" forces were reported.

6) Disorientation

A) Many subjects had "disorientation" sometimes called "vertigo," for example, flying inverted and not knowing it; ascribing a wrong turn to the target when pilot had actually made the turn.

B) Occurred most frequently during the formation task, because they were "off" their instruments more. Vertigo is caused by shifting eyes in-and-out.

7) Contact vs. Instrument Orientation

A) Some subjects were definitely more one than the other.

B) This may be related to having had jet vs. reciprocating engine training.

8) Disposition Toward Simulators

Generally favorable by all subjects. This may have been due to their having engaged in testing or experimental work of some sort.

9) Emergencies

A) Inside Cockpit Emergencies

(1) Many subjects used the failure of other aircraft instruments such as the "off" flag on the gyro-horizon, or the oil pressure gauge, to detect instrument inverter failure rather than the warning light which had been dimmed considerably for the experiment.

(2) Some subjects noticed that the emergencies (of which there were six) did not occur with equal frequency.

(3) Some subjects responded to emergencies prior to reporting them. This was contrary to instructions.

B) Outside Cockpit Emergencies

- (1) Some subjects were able to detect the projector bogie with peripheral vision.

10) Errors

A) Altimeter Errors

The altitude requested was 20,000 feet; the usual reading errors resulted in flying at 10,000, 22,000 and 30,000 feet.

B) Roll Reversal Errors

There was quite frequent initiation of roll in one direction and then a reversal.

C) Emergency Reporting

Piston engine pilots tended to refer to TPT as high cylinder head temperature.

D) Turn Error

Many subjects went left when asked to go right.

11) Special Difficulties (as reported by subjects)

- A) Some could fly well with target on left but not when target was on right.
- B) Aircraft too difficult to fly, too sensitive.
- C) Small control movement results in excessive target movement.
- D) Tendency to attribute movement to target--not to aircraft.
- E) Some subjects deviated from instructions just to see what would happen.
- F) Some S's turned away from target after holding position nicely for awhile.
- G) Some S's found target range information disturbing--others helpful. More S's thought it was helpful than not.

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H) Some confusion with gyro heading indicator--different in Naval aircraft than in Air Force aircraft.

I) Weird Experience

"Join up with target is unnatural--like a join up from outer space."

12) The lack of "g" forces acting on the pilot caused almost all pilots to exceed the red line with respect to "g".

EXHIBIT 3

CHECKLIST

A. Interior Check

1. Drag chute handle - OFF
2. Throttle - OFF
3. Speed brake switch - IN
4. Oil Cooler Shutter - AUTO
5. Master Switch - OFF
6. Air Start Switch - OFF
7. Fuel Regulator - NORM
8. Yaw damper - OFF
9. Windshield anti-ice - ON
10. Gear- DOWN
11. Hyd. gauge - No. 1
12. Generator - ON
13. Battery - ON
14. Power inverter - ON
15. Inst. inverter - 1 or 2
16. Sec bus tie-in - NORM
17. Fuel quantity - CHECK
18. Thunderstorm lights - As desired
19. Instrument lights - As desired
20. Console lights - As desired
21. Indicator - Caution - Warning Lights - TEST

B. Starting Engine

1. Master Switch - ON
2. Starter and ignition - PRESS
3. Throttle - IDLE at 12% to 16% rpm
4. Exhaust temp. - CHECK
5. Engine instruments - CHECK
6. Hyd. gauge - Flight Control 1 or 2
7. Hyd. gauge - No. 1
8. Speed brake switch - cycle - then IN
9. Trim - Operation - CHECK
10. Trim for takeoff.

C. Before Takeoff

1. Flight Controls - CHECK
2. Hyd. gauge - UTILITY

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3. Yaw damper - STANDBY
4. Takeoff trim - CHECK
5. Takeoff position and hold

D. Takeoff

1. Throttle - Military
2. Brakes - Release
3. Throttle - Afterburner
4. Engine pressure gauge - CHECK
5. Nose wheel - lift off
6. Takeoff attitude - Hold

E. After Takeoff

1. Gear - UP
2. Climb - Establish
3. Throttle - Inboard
4. Yaw Damper - ON
5. Throttle - Military - 350 knots

F. Before Landing

1. Fuel - CHECK
2. Speed brakes - As desired
3. Throttle - Adjust
4. Downwind - 230 knots IAS
5. Gear - DOWN
6. Base leg - Reduce to 190 knots
7. Final approach - 180 knots

G. Landing

1. Throttle - IDLE
2. Touchdown - 150 knots

H. Engine Shutdown

1. Speed brakes - OUT
2. Throttle - OFF
3. Master Switch - OFF
4. Battery Switch - OFF
5. Generator - OFF
6. Power Inverter - OFF

EMERGENCIES

A. Generator Failure

1. Switch secondary bus power to EMERG. position. Then NORM.

B. Inverter Failure

1. Switch to other inverter position.

C. Tail pipe temperature overheat.

1. Reduce throttle to idle and then slowly advance throttle (Check RPM).

D. Hydraulic failure (UTILITY)

1. Switch to No. 1 or No. 2.

E. Oil Cooler go OPEN 10 sec. then back to AUTO.

F. Windshield overheat. Turn to OFF position. Then ON later 10 sec.